Dryland Crops Research Stations in Eastern Oregon

Moro and Pendleton: 1909-2020

Richard W. Smiley

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Early History of Regions
Establishment and milestones of Stations
Research and Extension
Personnel and Publications
Early Documents

by

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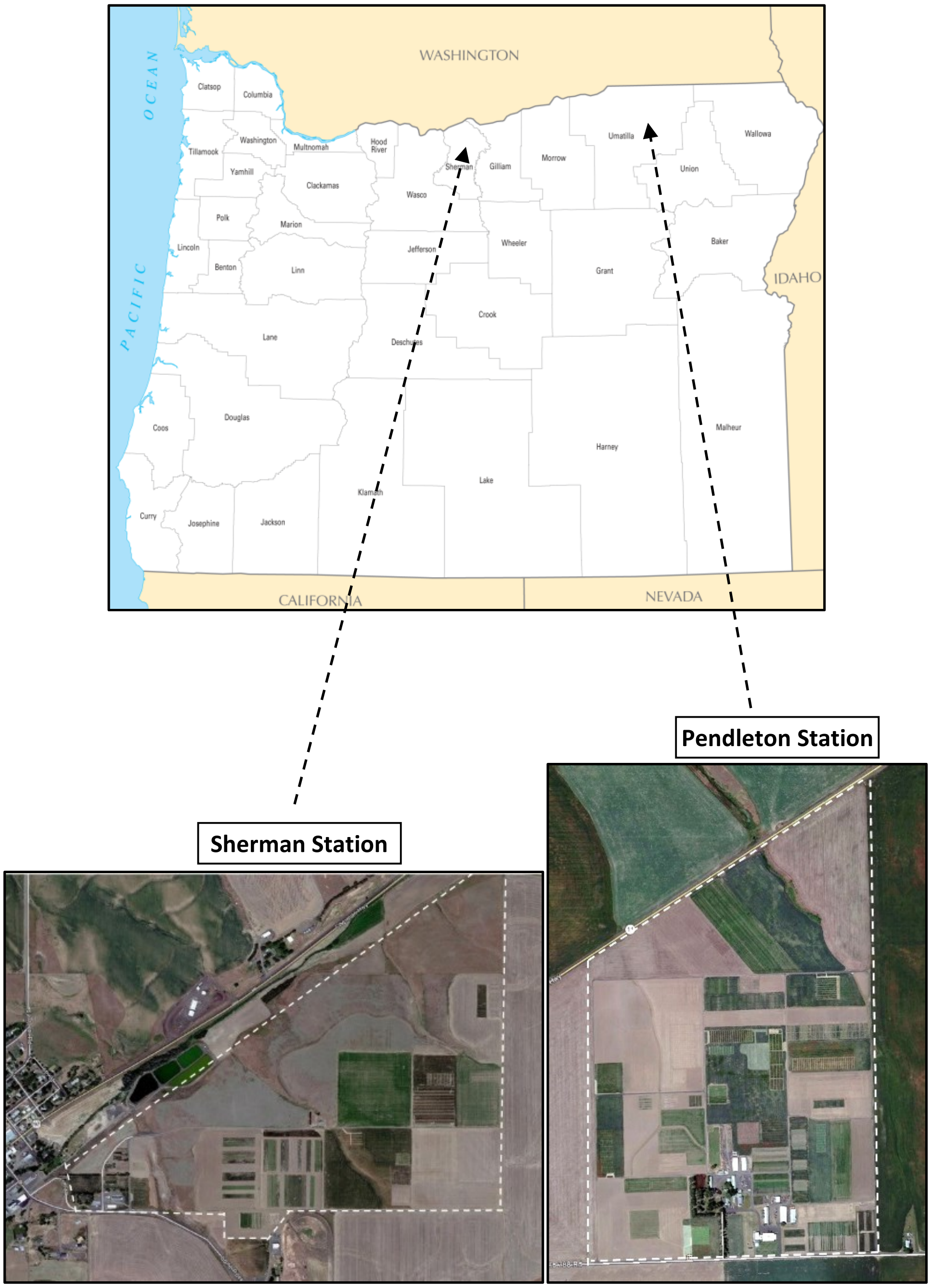

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Preface

The branch experiment stations at Moro (Sherman Station, established at Moro in 1909) and Pendleton (Pendleton Station, established near Adams in 1928) were founded by the Oregon Agricultural Experiment Station and the United States Bureau of Plant Industry (USDA-BPI) to conduct research that could support the livelihoods of farmers practicing dryland agriculture. These stations were merged administratively during the 1930s and then separated for three decades before, in 1973, being restructured again under the name Columbia Basin Agricultural Research Center (CBARC). While the USDA-Bureau of Plant Industry, Soils and Agricultural Engineering (the Bureau name when functions were transferred to the Agricultural Research Service in 1953) maintained a continuous presence at both stations, they too became organized as a distinct facility when the Columbia Plateau Conservation Research Center (CPCRC) was established at Pendleton during 1970.

Scientists at these stations and research centers have been addressing the needs of dryland agriculture in the Inland Pacific Northwest for more than a century. Farm families in eastern Oregon fully understand the meaning of 'dryland agriculture.' However, it may be important to define that term for the benefit of readers who are less familiar with the critical manner in which special climatic conditions in the region influence the types of crops that can be grown, and the limitations on how those crops can be managed. The climate of the Inland Pacific Northwest is the primary determinant of crops, production efficiency, and production stability from year-to-year.

What is dryland agriculture?

Numerous and quite different definitions exist for the term 'dryland agriculture.' The definition that will be most useful for this review was published by Dr. William Schillinger, Superintendent of the Dryland Agricultural Research Center at Lind, Washington. He is an agronomist who is renowned for his research in the driest climates of Washington. He also conducted research at the Sherman Station. Schillinger et al. (2006) defined dryland agriculture "*as that practiced where average annual precipitation is 600 mm* [24 inches] *or less and no irrigation is used*." They subdivided that definition because, without clarification, it describes 76 percent of all rainfed (non-irrigated) wheat production in the western U.S.. The definition distinguishes three precipitation zones: low (an average less than 12 inches), intermediate (12 to 18 inches), and high (18 to 24 inches). The climates near Moro and Pendleton are characterized as being in the low and intermediate zones, respectively.

Most definitions of dryland agriculture are far more technical. Some definitions include the seasonable distribution of precipitation, ratio of precipitation to potential pan evaporation, and the temperature that exists at the time the ratio is calculated (Stewart et al., 2006). One feature that is common to all definitions is that each of them define dryland agriculture as farming in regions where lack of moisture constrains crop production to a limited portion of the year, and is the over-riding factor responsible for low yields in areas that are seasonably dry. The climate in eastern Oregon is considered temperate (as opposed to oceanic or continental) and the precipitation occurs mostly during the coolest months from autumn through spring. Summer months are warm to hot and are nearly lacking in rainfall events of sufficient magnitude to wet the soil to a depth where it can be taken up by plant roots. This feature of the climate in eastern Oregon differs greatly from important agricultural areas such as the Great Plains, where total precipitation is often similar that that in eastern Oregon, but is distributed much more uniformly into the summer months, at the time when crops are maturing. For that reason alone, many crops that are productive in the Great Plains do not grow well in eastern Oregon. Most cropping systems that are efficient in areas which receive summer rainfall are totally ineffective in eastern Oregon. Dryland agriculture in temperate climates is dominated throughout the world by production of wheat, barley, sorghum and millet (Dregne, 2006). Winter temperature dictates whether spring wheat or winter wheat is the dominant crop in the cool-temperate regions. These unique characteristics and differences of climate and weather are exceedingly important for understanding the results of research on rainfed crops in northcentral and northeast Oregon.

Purpose of this book

From the times of their inceptions, the stations and centers in eastern Oregon have earned international recognition for their great contributions to the development of dryland agricultural systems. Results of research in eastern Oregon are therefore respected and well recognized by scientists working in similar climatic regions throughout the world. General summaries of research accomplishments from these stations have been published. The most recent of summary was published in 1961 for the Sherman Station (Hall, 1961) and, in 1995, for the Pendleton Station (Pumphrey and Rasmussen, 1995). However, those summaries were very short and lacked detail; 16 and 38 pages, respectively. A more comprehensive summary of contributions from these stations and centers has not been published.

Even a superficial evaluation of research at the stations and centers reveals experiments that have been repeated at 2- to 3-decade intervals, or whenever sufficient time has passed to have allowed the 'corporate memory' to become faded or absent. While some repetition is essential as new technologies and varieties are developed, it is notable that the broad findings of more recent repetitious studies have been nearly identical to what had been discovered decades or even a century earlier. Without historical insight, attribution or recognition, the recent experiments not only fail to benefit from earlier studies, but the more recent funding agencies are allocating research funds in an inefficient manner. The philosopher George Santayana (1932) stated that *"When experience is not retained, as among savages, infancy is perpetual. Those who cannot remember the past are condemned to repeat it."* Santayana's vision is pertinent to research at the dryland research stations and centers in eastern Oregon.

The Sherman Station was still a leader in dryland agricultural research and had a full complement of local staff when the most recent summary was published from that location in 1961 (Hall, 1961). During the early years, the Pendleton Station was operated as a satellite of the Sherman Station. During the past five decades the once-independent Sherman Station became a satellite of the Pendleton Station. During that transition the staffing level at the Sherman Station was reduced from as many as four scientists and five other staff members to a single full-time employee at the present time. Research activities at the Sherman Station are now directed and mostly operated by scientists and staff based in Pendleton and Corvallis, Oregon, and in Pullman, Washington.

The Oregon Agricultural Experiment Station (OAES) has also experienced an important transition. Branch experiment stations once focused on research that solved regional problems. During the past three decades, most stations were converted to an increasing focus on extension education. Research productivity at some stations has therefore declined in recent decades. The Columbia Basin Agricultural Research Center (CBARC), with stations at Moro and Pendleton, is an example of a branch experiment station where the focus on research has become diminished.

A comprehensive summary of research at the Sherman and Pendleton Stations is also needed because records are no longer retained by these stations. Invoices and written correspondence to and from station administrators and scientists were retained prior to about 1970. Detailed annual reports were prepared by the stations until 1972. From 1974 until 2010, periodic summaries of selected research projects were reported in the form of published 'Special Reports.' Those reports were submitted on a voluntary basis, so an important portion of research actually conducted was not reported to growers and other interested individuals during that 36-year period. Therefore, detailed record keeping ceased in about 1972, detailed reports of staff meetings and liaison committee meetings ceased in about 2003, and periodic written reports for use by growers and other interested parties ceased in 2010. As in the past, verbal communications continue in the form of field tours, visits to individual farms, and winter conferences. Written reports are now almost exclusively as technical manuscripts published in professional journals. Very few extension bulletins are published. Social media has become a strong area of emphasis, but provides for no permanent documentation. None of the recent communication styles provide historically important information regarding new personnel, new or terminated research projects, equipment purchases, construction and demolition, or progress in yet-to-be concluded projects. The 'corporate memory' is being lost. The goal of this book is to summarize the histories of the dryland stations and research centers, including a listing of peer-reviewed publications, since 1909. The book is intended as a resource for those who may wish to explore certain topics at greater depth. A guiding principle while preparing the most of the text was 'if the research wasn't formally documented, it probably didn't happen.'

The author claims no deeper insights into past contributions of these stations than other scientists and staff members who have also served at these locations. However, the author was the most recent of the long-serving administrators. He served as Director of CBARC for 16 years, continued to conduct research for another 15 years, and continues to report previous research after retiring in 2015. The author's 35 years of service at these stations was similar in length to three earlier administrators, David Stephens, Merrill Oveson, and George Mitchell. Stephen's administered the stations for 26 years, from 1912 until 1938. Oveson and Mitchell also served at both stations; Oveson for 38 years (1928-1966) and Mitchell for 32 years (1921 until 1953).

Some experiments summarized in this book were briefly reviewed previously. Examples include pamphlets or bulletins by Oveson (1940), Stephens (1944), Oveson and Hall (1957), Horning and Oveson (1962), Oveson and Besse (1967), Rasmussen and Smiley (1994), and Pumphrey and Rasmussen (1995).

Acknowledgements

Most images were from archived photographs at the OSU Columbia Basin Agricultural Research Center and the USDA-ARS Columbia Plateau Conservation Research Center. Other images were from publications and reports by those centers, and from personal collections of current and former scientists and staff affiliated with Oregon State University and USDA-Agricultural Research Service. Many images archived at the Sherman Station are originals provided by Mr. Chet Coats, father-in-law of Erling Jacobsen, a former farm manager at that Station. Others who provided images or material assistance for this publication included the Sherman County Extension Service (Sandy Macnab), Umatilla County Extension Service (Patricia Dawson, Michael Stoltz and Shevon Hatcher), Sherman County Historical Museum (Sherry Kaseberg, Patti Fields and Lowell Smith), Umatilla County Heritage Station Museum (Susan Olson and Tami Johlke), OSU Valley Library Special Collections and Archives Research Center (Rachel Lilley), Agri-Times Northwest newspaper (Sterling Allen), EO Media Group (East Oregonian and Capital Press newspapers; Chris Rush and Kathryn Brown), Mary Oveson Stoddard (daughter of Merrill and Mal Oveson), Laurie McDermid Barker (daughter of Jack McDermid), Arnold Appleby (OSU Emeritus Professor), Sherman Station farm managers (Erling Jacobsen and Kyle Bender), Pendleton Station farm manager (Karl Rhinhart), Columbia Basin Agricultural Research Center (Debbie Sutor and Susan Philips), and Columbia Plateau Conservation Research Center (Drs. Daniel Long and John Williams, and Tami Johlke).

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The author is especially appreciative of support and encouragement by Dr. Daniel Long, Research Leader of the USDA-ARS unit at Pendleton, who provided the author space and resources to continue working at the research center while continuing his writings and collaborations following retirement. Dr. Long also provided a technical review of important chapters in this book. The author also appreciated on-going support from the Columbia Basin Agricultural Research Center, which contributed office and material support while the author served as a 'volunteer' in addition to his role as Emeritus Professor.

The author also expresses heartfelt thanks for research assistance, moral support, editing, patience and encouragement by and from Marilyn Smiley and Elizabeth Smiley.

All proceeds from sales of this book, if any, will be directed to the Oregon State University Foundation, whereupon the fund will be distributed equally into the Sherman Station Endowment and the Pendleton Station Endowment.

Searchable format

An electronic copy of the author's research notes and of this book are available from the author (richard.smiley@oregonstate.edu) and the Columbia Basin Agricultural Research Center, 48037 Tubbs Ranch Road, Adams, Oregon 97801 (https://agsci.oregonstate.edu/cbarc).

***References*:**

Baker, G. L., W. D. Rasmussen, V. Wiser, and J. M. Porter. 1963. Century of Service. Page 478. The first 100 years of the United States Department of Agriculture. U.S. Government Printing Office, Washington 25, D.C. 560 pages.

Dregne, H. E. 2006. Historical perspectives. Pages 27-38. In: *Dryland Agriculture*, 2nd edition (G. A. Peterson, P. W. Unger, and W. A. Payne, editors). Agronomy Monograph No. 23, American Society of Agronomy, Madison, Wisconsin. 928 pages.

Hall, W. E. 1961. Fifty Years of Research at the Sherman Branch Experiment Station. Oregon Agricultural Experiment Station Miscellaneous Paper 104. 16 pages.

Horning, T. R., and M. M. Oveson. 1962. Stubble Mulching in the Northwest. USDA Agriculture Information Bulletin No. 253. U.S. Government Printing Office, Washington, D.C., and Oregon Agricultural Experiment Station, Corvallis, Oregon. 28 pages.

Oveson, M. M. 1940. Examples of Accomplishments and Projects at the Sherman Branch of the Oregon Agricultural Experiment Station in Cooperation with the U.S. Bureau of Plant Industry from 1909 to 1940. An Unpublished Station Summary. 8 pages.

Oveson, M. M., and R. S. Besse. 1967. The Pendleton Experiment Station: Its development, program and accomplishments … 1928 to 1966. Oregon Agricultural Experiment Station Special Report 233. Corvallis, OR. 20 pp.

Oveson, M. M., and W. E. Hall. 1957. Longtime Tillage Experiments on Eastern Oregon Wheat Land. Agricultural Experiment Station Technical Bulletin 39, Oregon State College and U.S.D.A.-Agricultural Research Service, Corvallis. 47 pages.

Pumphrey, F. V., and P. E. Rasmussen. 1995. The Pendleton Agricultural Research Center, 1967-1992. Oregon Agricultural Experiment Station Special Report 950. 38 pages.

Rasmussen, P. E., and R. W. Smiley. 1994. Long-term management effects on soil productivity and crop yield in semi-arid regions of eastern Oregon. Oregon Agricultural Experiment Station Bulletin 675. 57 pages.

Santayana, G. 1920. Flux and constancy in human nature. Pages 269-291. In: Chapter 12 of The Life of Reason: Reason in Common Sense. Charles Scribner's Sons, New York. 291 pages.

Schillinger, W. F., R. I. Papendick, S. O. Guy, P. E. Rasmussen, and C. Van Kessel. 2006. Dryland cropping in the western United States. Pages 365-393. In: Dryland Agriculture, 2nd edition (G. A. Peterson, P. W. Unger, and W. A. Payne, editors). Agronomy Monograph No. 23, American Society of Agronomy, Madison, Wisconsin. 928 pages.

Stephens, D. E. 1944. Effect of tillage and cropping practices on runoff, erosion, and crop yields in the wheat growing areas of Washington, Idaho, and Oregon. Pages 1-105 in D. E. Stephens, Conservation Practices on Wheat Lands of the Pacific Northwest. U.S.D.A. Soil Conservation Service, Pacific Coast Region ·· Seven. Washington, D.C. 125 pages.

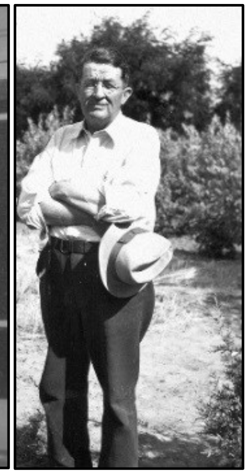
Stewart, B. A., P. Koohafkan, and K. Ramamoorthy. 2006. Dryland agriculture defined and its importance to the world. Pages 1-26. In: *Dryland Agriculture*, 2nd edition (G. A. Peterson, P. W. Unger, and W. A. Payne, editors). Agronomy Monograph No. 23, American Society of Agronomy, Madison, Wisconsin. 928 pages.

Dedication

This book is dedicated to David Stephens, Merrill Oveson and George Mitchell, the first three long-serving administrators of the dryland experiment stations at Moro and Pendleton, Oregon. Their leadership for more than four decades positioned them, individually and collectively, to become recognized as the most influential leaders of early programs and facilities at these stations. Work at the stations continues to be influenced by these three early administrators. Each of them were agronomists in the Bureau of Plant Industries, of the U.S. Department of Agriculture. As importantly, they were amply assisted and supported in their service to agriculture and their communities by each of their wives and children. The Stephens, Oveson and Mitchell families are fully deserving of this recognition and dedication.

(1925)

(1938)
(Dave & Kate with Mary Oveson)



(1938)

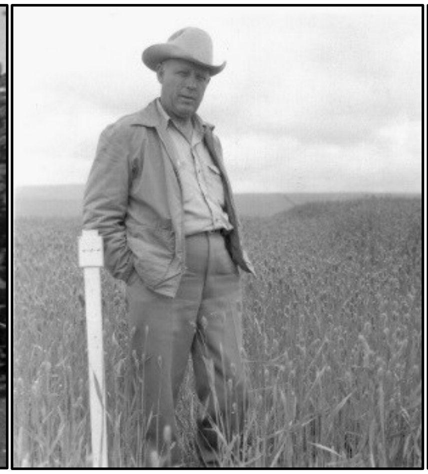
David Edmund Stephens (1879 – 1946)
Superintendent of the Sherman Station: 1912 - 1938
Superintendent of the Pendleton Station: 1928 - 1938

Dave Stephens was born on June 12, 1879 in Malad, Idaho. He married Catherine Izatt on June 12, 1906 in Logan, Utah. They parented four children: Edmund, Thomas, Emmajean and Janet. Dave earned a degree in agronomy from the University of California and taught courses at Utah Agricultural College. He was employed by the USDA in Washington, D.C. before being transferred to Moro, Oregon in 1912. He became the first long-serving administrator of the Sherman Station. Dave and Kate became deeply involved in the Sherman County community. He administered both stations after the Pendleton Station was established. They continued to reside in Moro. In 1938, the USDA transferred Dave back to Washington, D.C. In 1942, he and his family moved to Pullman, Washington, where he became employed by the USDA-Soil Conservation Service. At age 67, on December 10, 1946, David passed away from heart-related complications following tooth surgery at Colfax, Washington. One month later, on January 10, 1947, Kate passed away, at age 64. Dave and Kate are buried at Lincoln Memorial Park in Portland, Oregon.

"*The Columbia Basin wheat farmer owes much to Dave Stephens because his work focused attention on ways to increase wheat yields and to make wheat production more certain. The classic experiments at the Moro station have furnished the entire world with the fundamentals of dryland agriculture*."

From Dr. Donald D. Hill's address "*The Oregon Wheat Research Program,*" at the 19th Annual Meeting of the Eastern Oregon Wheat League, La Grande, OR, December 16, 1946; that meeting occurred days after Stephens' passing and led to formation of the Oregon Wheat Commission. Hill was Chair of the Department of Farm Crops at Oregon State College.


(1939)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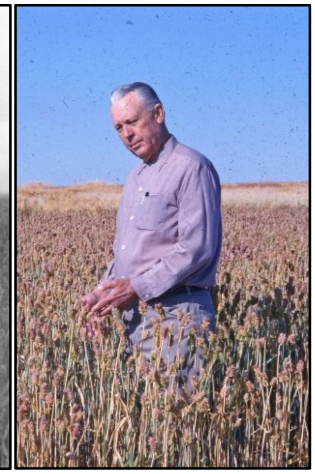

(ca. 1960)

Merrill Mahonri Oveson (1900 - 1981)
Superintendent of the Sherman Station: 1938 - 1948
Superintendent of the Pendleton Station: 1948 - 1966

Merrill Oveson was born on November 7, 1900 in Castle Dale, Utah. He married Mal Berg on September 7, 1927 in Salt Lake City, Utah. They parented four children: Richard, Joan, Steven and Mary. Merrill earned a master's degree at Oregon State College and then, in 1929, he became employed as an agronomist at the Sherman Station. He was promoted to the administrative role of Station Superintendent upon Dave Stephen's departure in 1938. The Station residence burned in 1947, with a total loss of the Oveson family's belongings. Shortly thereafter, in 1948, Merrill was transferred to the Pendleton Station and served as the Superintendent and agronomist at that location. The Oveson's became fully involved in each of the Oregon communities in which they lived. After Merrill retired in 1966, he and Mal served a two-year mission for their church. They then moved to Amman, Jordan, where Merrill worked for 18-months as an agronomist for an Oregon State University contract with the U.S. Agency for International Development. At age 80, Merrill passed away in Tempe, Arizona on July 11, 1981. At age 102, on March 21, 2005, Mal Oveson died in Provo, Utah. She and Merrill are buried in the cemetery at Castle Dale, Utah.

(1921)

(1934)

(Gwen at a field tour - 1987)

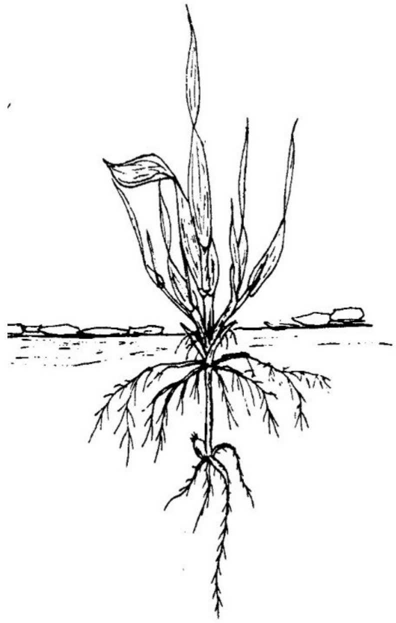
George Adamson Mitchell (1892 - 1979)

Assistant Superintendent of the Pendleton Station: 1928 - 1938
Superintendent of the Pendleton Station: 1938 - 1948
Superintendent of the Sherman Station: 1949 - 1953

George Mitchell was born on June 12, 1892 in Victoria, Canada. He served in the U.S. Army during World War I and became an agronomist at the Sherman Station in 1921. George married Gwendolyn Lucille Reese, a teacher at Moro High School, on June 14, 1925 at Monkland, in Sherman County, Oregon. They parented two daughters and one son: Mary Ann, Carol Jane and Thomas. In 1928, George was transferred to Pendleton to become the Assistant Superintendent of the yet-to-be established Pendleton Station. He coordinated development of the new station's infrastructure and experimentation. George and Gwen also established a landscape plant-testing program at Pendleton. Their gardens included multitudes of species and varieties of trees, shrubs and flowering ornamentals. Gwen's passion for horticulture led to the chrysanthemum, lily and rose gardens becoming recognized for excellence locally. They became a regional tourist attraction. In 1948, George Mitchell was moved back to Moro, where he came Superintendent of the Sherman Station. He retired in 1953, whereupon the Mitchell's moved to Helix, in Umatilla County. George and Gwen each continued to participate in field days at the stations. At age 87, on March 10, 1979, George passed away in Walla Walla, Washington. Gwen continued serving the community and in state and regional politics. She spent two sessions working for the Oregon State Legislature in Salem. She became an strong advocate for social issues. Gwen continued to attend field tours and to counsel Superintendents of the Pendleton Station into her late 80s. Gwen passed on March 24, 1999, at the age of 97. The Mitchell's are buried in the cemetery at Helix, Oregon.

List of Common Abbreviations

AAA	USDA, Agricultural Adjustment Act
C:N ratio	Carbon-to-nitrogen ratio in plant tissues
CBARC	Columbia Basin Agricultural Research Center (Oregon Agricultural Experiment Station)
CIMMYT	International Maize and Wheat Improvement Center
CPCRC	Columbia Plateau Conservation Research Center (U.S. Department of Agriculture)
CRP	USDA, Conservation Reserve Program
CTUIR	Confederated Tribes of the Umatilla Indian Reservation
GDD	Growing-degree days (heat units for plant growth)
OAES	Oregon Agricultural Experiment Station, at Corvallis, OR
OES	Oregon Extension Service, at Corvallis, OR
OR&N	Oregon Railway and Navigation Company
OSU	Oregon State University
pH	An index of acidity, as for soil pH
RUSLE	Revised Universal Soil Loss Equation
U.S.	United States
USDA	United States Department of Agriculture
USDA-ARS	USDA, Agricultural Research Service
USDA-BPI	USDA, Bureau of Plant Industry
USDA-NRCS	USDA, Natural Resources Conservation Service
USDA-SCS	USDA, Soil Conservation Service
USLE	Universal Soil Loss Equation



Chapter 1 - Development of Agricultural Experiment Stations

Europe

An introduction to 'scientific agriculture' in the United States was strongly influenced by pioneering programs in European nations such as Scotland, Germany and England (Kerr, 1987). Of particular importance was the influence of Justus von Liebig, a German scientist who, in 1840, published a treatise on "*Organic Chemistry In Its Application of Agriculture and Physiology*." Liebig predicted that discoveries from the scientific analysis of plants and soils could explain plant growth. He also advocated that permanent soil fertility could be achieved by restoring a proper balance of nutrients necessary for plant growth. His followers predicted that methods for analyzing soils could be perfected and that prescriptive treatments could be applied to individual fields.

While most farmers at that time had an absolute distrust for science as it might be applied to agriculture, several events began to cause a slow evolution in thoughts among farmers. In 1842, a group of progressive farmers in Scotland hired James Johnston to conduct laboratory experiments and to deliver educational lectures in support of the farmers' own field experiments. The goal was to improve crop productivity by improving soil fertility. A year later, in England, a student of Liebig was hired to coordinate farming programs on Sir John Lawes' Rothamsted estate in England. Shortly thereafter, in 1852, the first publicly funded agricultural testing station was established at Moeckern, Germany, by the government of the State of Saxony. The many successes from the agricultural research at Moeckern quickly led to more than 70 such stations in Germany. These stations emphasized laboratory investigations that were independent of the nation's academic institutions.

United States

Many American students and scientists visited the practical agricultural research programs in Europe and returned home invigorated with these new concepts for agricultural research and farmer education in the United States. One of the scientists was John Norton, who traveled to Scotland in 1844 to study under the leadership of James Johnston (Kerr, 1987). Norton returned to Connecticut in 1846 and established a teaching laboratory where he strongly advocated for a new approach to effective agricultural education. His efforts were thwarted because he failed to overcome the farmers' distrust of "book farming." Nevertheless, some headway toward achieving that goal was gained when one of Norton's students, Samuel Johnson, returned from a visit to the agricultural research station at Moeckern, Germany. Johnson also failed in his campaign to establish a Moeckern-style research and education program for farmers, but he advanced the cause indirectly when he succeeded in overcoming some of the farmers' distrust for science. He did so by analyzing fertilizers being sold to farmers during the late 1840s. As soon as soil enrichment products began to be sold for agricultural purposes, it became clear that many of the offerings were fraudulent 'miracle products.' Johnson assuaged the outrage of victims by providing scientific analyses of the commercial products and, by 1857, he became appointed to a new position of chemist for the Connecticut State Agricultural Society. Johnson intended to use his new platform of protecting consumers from fraud to expand his duties into a full-scale experiment station modeled after the German program. Unfortunately, Johnson's chemist position was eliminated as a casualty of the Civil War. After the war, he continued his campaign for science in the service of agriculture by joining forces with other movements having similar objectives.

At about the same time, during the Civil War, there were few or no southern obstructionists remaining in the U.S. Congress. That lapse enabled the Republican Party to repay its political debt to Midwest farmers by enacting a series of bills called the "Farmers' Legislation." Among the bills signed into law by President Abraham Lincoln in 1862 was a Homestead Act and a Transcontinental Railroad Act. Both bills assisted farming by encouraging settlement of new lands and assuring improved access to markets. At that same time, Americans were gaining an increasing regard for additional education, but not in the style of the elitist English model being practiced at that time by existing universities. The demand by the American public was for practical aspects of education, and for government-sponsored vocational higher education.

After several initial failures during 1857 and 1859, a bill was re-introduced to Congress in 1862 by Justin Morrill, a Representative from Vermont. The title of the bill was "*Act of 1862 Donating Lands for Colleges of Agriculture and Mechanic Arts*." What came to be known as the Morrill Land-Grant College Act, signed by President Lincoln, promised each state 30,000 acres of public land for each of its Senate and

House members. But most states did not have that much unsold public land and they were given scrip to the public domain in those states that did have sufficient unsold acres. Each state was directed to use its money as a trust fund to endow a college where practical education in agriculture and engineering would be emphasized (Kerr, 1987). Because of low land prices following the Civil War, and of passage of the Homestead Act, most states sold their entitlement to dealers and enacted legislation to establish new agricultural and mechanical colleges that were separate from existing state universities. This caused states to suddenly become burdened by the economic necessities for supporting two colleges. In 1872, Morrill, then a Senator, again came to the rescue by proposing the Second Morrill Act. That Act became enacted in 1890 and provided for direct annual Federal appropriations to each state to support its land-grant college.

During the interim, farmers became frustrated as many colleges attempted to satisfy the mandate of the Land-Grant College Act by simply adding an agricultural chemistry course to the existing curriculum. Under duress, many colleges were forced to establish a demonstration farm to meet farmers' expectations and demands for visible evidence of the colleges' commitment to their well-being. By 1875, experiments were also being conducted in the countryside, often consisting only of a test plot to evaluate combinations of crops and fertilizers, with supporting chemical analyses being performed in the college laboratory.

Samuel Johnson's earlier work as a chemist with the Connecticut State Agricultural Society began to yield dividends. In 1869, post-war recession led to Johnson's appointment as the state chemist for the Connecticut Board of Agriculture. He then reinvigorated his campaign for a German-styled research institution. The Board of Agriculture introduced a bill in 1875 to finance a laboratory of that type at public expense and under control of the Board. By 1876 the Connecticut Agricultural Experiment Station was formed, using the same nomenclature as the experiment station at Moeckern, Germany. That was the first American agricultural experiment station. Wilbur Atwater, a former student of Johnson, became the first director of the first experiment station. Johnson became the second director. The station was highly independent from academic pursuits.

In 1871, representatives of a dozen state colleges gathered in Chicago to have a convention with the theme "Friends of Agricultural Education." That meeting led to the encouragement of establishing agricultural experiment stations as adjuncts to the state land-grant universities. A committee was appointed to take that proposal to the state legislatures and to Congress. The next year, the United States Department of Agriculture assumed the responsibility for holding a follow-up meeting in Washington, D.C. Delegates from 32 states and three territories participated, primarily to unite behind the second Land-Grant College Act being proposed in 1872 by Senator Morrill. As before, a committee was appointed to propose a way to establish agricultural experiment stations in all states. Another meeting on this topic did not take place until a decade later. A new federal Commissioner of Agriculture called for a convention of agricultural colleges and farmer organizations in 1882. The need for agricultural experiment stations was among the topics to be addressed. No formal action was taken at that time but in 1883, at a follow-up convention, more decisive action was taken when the body endorsed a current proposal, from Iowa, to provide federal funding for agricultural experiment stations that were connected with state agricultural colleges. A committee was formed to lobby for passage of the bill. The bill continued to move through Congress but became almost entirely revised during the process. It was ultimately enacted as the Hatch Act in 1887, and was signed by President Grover Cleveland. The title of the bill was "*Act of 1887 Establishing Agricultural Experiment Stations*." The experiment stations were to "*aid in acquiring and diffusing among the people of the United States useful and practical information on subjects connected with agriculture, and to promote scientific investigation and experiment respecting the principles and applications of agricultural science*." "*… it shall be the object and duty of said experiment stations to conduct original researches or verify experiments on the physiology of plants and animals, … diseases … and remedies, … advantages of rotative cropping, … capacity of new plants or trees for acclimation, … analysis of soils and water, … chemical composition of manures, natural and artificial, and their comparative effects on crops, … adaptation and value of grasses and forage plants, … and such other researches or experiments bearing directly on the agricultural industry of the United States …*" (Kerr, 1987). Each state was appropriated $15,000 to establish and maintain their agricultural experiment station. By 1887, primarily through prompting by Atwater and Johnson, agricultural experiment stations had become established in 14 states. All stations were structured somewhat differently but the ideals were similar.

Oregon already had a land-grant college that was established two decades earlier. Oregon, therefore, accepted the Hatch Act offer in 1888, the first year that money became available. In 1888, at least 13 states in the U.S. already operated off-campus research sites staffed by agricultural experiment station personnel.

By 1909, there were 28 branch stations at off-campus locations across the Nation, including one at Union, Oregon. By 1914, there were about 70 off-campus locations in 30 states, and that number grew to 130 branch stations in 1920. Those off-campus demonstration and research sites proved more popular than scientists or specialists traveling from a central location to enlist the aid of cooperating farmers. However, in the early years, the off-station locations in agricultural regions were often no more enduring than the travel-based model used earlier (Kerr, 1987). But, branch stations could and did provide opportunities for longer-term, supervised investigations on soil types and under climatic conditions not available at a central station.

In 1902 the Department of Agriculture, Office of Experiment Stations, appropriated $2,000 to develop course outlines, train lecturers, and suggest speakers for meetings called 'Farmers' Institutes.' The institute concept involved a series of traveling lecture programs, as had been practiced since the 1860s, or a series of agricultural short courses at the university campus. In 1914, nearly 9,000 institutes were held across the nation and the programs involved nearly 600 (one third) of the station scientists. As institutes matured and their audiences became more sophisticated, an ever increasing amount of time by station scientists was expected to be spent on the lecture circuit rather than on their obligation for experimental work. As a result, much of the effort at the experiment stations shifted from a focus on replicated experiments to a focus on non-replicated demonstrations. Rulings in 1904 and 1909 restricted and then forbade Hatch Act support for the delivery of practical information to farmers through findings from non-replicated demonstrations. Beginning in Texas, in 1904, extension agents began to visit farms to convince leading farmers to use a portion of their acreage for demonstrations. These efforts were funded jointly by the U.S. Department of Agriculture (USDA), private philanthropic foundations, and local governments. In return, the experiment stations were called upon to discover and extend useful information on issues of local importance. This extension of research findings became formalized nationally by the Smith-Lever Agricultural Extension Act of 1914. The Act established a national system for rural adult vocational education, and for agents in the counties.

Oregon

Corvallis College was a private liberal arts college founded by the Methodist Church in 1858. It became designated as the Agricultural College of the State of Oregon in 1868, in order to allow the State's Legislative Assembly to accept a grant of land under the Morrill Act of 1862 (Lovell et al., 1990). A provision of the Morrill Act was that the College would be obligated to provide instruction in agriculture as well as in the then-current disciplines taught at Corvallis College. Benjamin Arnold was appointed President of the College in 1872 and he immediately lobbied for, and received, additional State funds to provide additional support for the new Land Grant institution. Nevertheless, the transition to fulfill the new teaching mission languished for nearly a decade due to insufficient funding and a "*decided lack of interest in scientific agriculture*." The Morrill Act also required the College to establish and to operate an experimental farm. In 1871, Benton County donated a 35-acre farm to fulfill this requirement. Few improvements were made, again because of fiscal constraints. As in most other states, little or nothing was being done to conduct scientific experiments in agricultural science.

In 1884, President Arnold cited the work of experiment stations in Europe and the move to enact a bill before Congress to establish similar experiment stations in the United States. He asked the Oregon Legislature to urge Congress to pass the bill, but the Oregon legislature did not do so. The State assumed control of the College when that role was relinquished by the church in 1885 and, after the State took control, the name of the institution was officially changed to Oregon Agricultural College, with governance being guided by a Board of Regents. In 1886, President Arnold renewed his attempt to acquire state support for federal legislation that would enable and coordinate agricultural experiment stations. The Hatch Act was passed and signed early in 1887. Allocation of $15,000 federal dollars would increase the total operating budget of the Oregon Agricultural College by more than 50 percent (Lovell et al., 1990). In 1988, College President Arnold and his staff began organizing the 35-acre farm for experimental research. However, the Oregon Legislative Assembly did not pass the required enabling legislation until early 1889.

Enabling legislation to establish the Oregon Agricultural Experiment Station (OAES) was signed by Governor Sylvester Pennoyer on February 25, 1889. Edgar Grimm, the first Director, was a professor of chemistry and agriculture, and taught courses in practical agriculture, fruit culture, botany, as well as more traditional courses in chemistry (Anon., 2016). Grimm also supervised research being done on two acres of the farm, and in 1888 he wrote the first bulletin released by the Station, before the Station was formally established. In 1889, Grimm also expanded the college farm to 155 acres and acquired donations of four cattle breeds to establish research herds. By 1890 the OAES was publishing bulletins on a wide range of topics to help farmers solve problems involving hog production, weed control, pasture irrigation, soil improvement, selection of the best crops and varieties, and constructing efficient buildings. During the first decade, seven staff members had released 58 informational bulletins and circulars.

In 1890, College President Benjamin Arnold assumed the additional role as Director of the OAES. When Arnold retired in 1892, the position of Director of the OAES was assumed by incoming President John Bloss. The dual roles of President and Director were held by H. B. Miller during 1896 and 1897, and by Thomas Gatch from 1897 to 1907. It was under Gatch's administration that the branch experiment station was established at Union, in northeast Oregon, during 1901, and that the Department of Agriculture, Office of Experiment Stations, appropriated $2,000 in 1902 to develop course outlines, train lecturers, and suggest speakers at Farmers' Institutes.

William Jasper Kerr became President of the College and Director of the OAES in 1907. Shortly thereafter, in 1908, he assigned James Withycombe as the Director of the Experiment Station (Anon., 2016). It was during Withycombe's tenure as Director that the branch experiment stations at Moro and Hermiston were established in 1909 (Anon., 1937 and 2016; Lovell et al., 1990). Kerr served as the College President until 1932 and Withycombe transitioned from the position of Director to become Governor of the State of Oregon in 1914. He was succeeded as Director of the OAES by A. B. Cordley (1914-1920) and by James T. Jardine (1920-1931). It was under Jardine's leadership that the branch experiment station near Pendleton was established.

References:

Anon. 1937. *The First Fifty Years of the Oregon Agricultural Experiment Station, 1987-1937*. Oregon State College Station Circular 125, Corvallis. 28 pages.

Anon. 2016. *Oregon Agricultural Experiment Station History*. http://agsci.oregonstate.edu/research/oregon-agricultural-experiment-station/oaes-history.

Kerr, N. A. 1987. *The Legacy: A Centennial History of the State Agricultural Experiment Stations: 1887-1987*. Missouri Agricultural Experiment Station, Columbia. 318 pages.

Lovell, R. P., A. Duncan, and R. L. Floyd. 1990. *100 Years of Progress: The Oregon Agricultural Experiment Station, Oregon State University, 1888-1988*. Oregon Agricultural Experiment Station Miscellaneous 89:3, Corvallis. 154 pages.

Chapter 2 - Sherman and Umatilla Counties before the Branch Experiment Stations

Agriculture and society were well established in north-central and northeast Oregon before the dryland branch experiment stations were founded. Many aspects of the regions, people and agriculture influenced the placement of these stations. A brief review of some of those factors explains what had occurred and was occurring when the stations were established in Sherman and Umatilla counties.

Native People

The native people who inhabited lands in and near present-day Sherman County sustained themselves mostly by fishing, hunting, and foraging for edible native plants (French, 1958). They were affiliated mostly with the Columbia Basin Tenino and Wyam tribes (https://www.co.sherman.or.us/sherman-county-history/). Most of these early inhabitants focused their interests on the bountiful fishery of the Columbia River. They hunted game in the uplands that now form the basis of the wheat industry in present-day Sherman County. These native people also used the uplands for travel to the fisheries and to the trading center at Celilo Falls, west of present-day Sherman County.

In contrast, the lands of present-day Umatilla County were thoroughly inhabited and used by people of the Walla Walla, Umatilla and Cayuse tribes. The Walla Walla and Umatilla were river people who occupied both sides of the Columbia River and prospered with an abundance of native plants and wild game and fish (CTUIR, 2017; Karson, 2006). The Cayuse were initially tributary fishermen but after the arrival of the horse they lived throughout the lower Columbia Plateau from the Cascade Mountains to the Blue Mountains. They grazed horses on the abundant grasses of southeast Washington and the Deschutes-Umatilla Plateau. The people on the Columbia Plateau were multi-lingual, speaking several languages, dialects and trade jargons, and later French and English. They were very influential in regional economics and politics due to their key geographical setting. These people were key middlemen for trade between the buffalo country of the Great Plains and the rainforest and ocean resources of the Pacific Coast. Trade and barter was essential for their survival. An elaborate and complex Indian civilization flourished on the Columbia Plateau.

The native people owned tens of thousands of horses. They needed to spread them over large areas to graze on the lush bunch grasses without causing the grasslands to deteriorate. They grazed horses all across the Umatilla Basin and northward for more than one hundred miles along the Columbia River Valley, for 100 miles to the southeast including the Grande Ronde and Baker valleys, and 100 miles to the south of present-day Pendleton, and all the way west to the Cascades Mountains. The horse expanded the culture of the three tribes, and the improved mobility brought them into contact with other Indian cultures in far distant lands including present-day Montana and Wyoming to the east, Canada to the north, California and Nevada to the south, and throughout the Pacific Northwest.

The United States ‘bought’ from the French vast amounts of land east of the Rocky Mountains during the "Louisiana Purchase" in 1803. Immediately thereafter, President Thomas Jefferson organized the Corps of Discovery Expedition that sent Lewis and Clark to explore the purchased land and to strengthen the United States claims on the ‘unclaimed’ lands between the Rocky Mountains to the Pacific Ocean. The first Europeans that interacted with Indian people in present-day Oregon and Washington were in that expedition, which moved from the Snake River and into the Columbia River during October 1805. The explorers returned the following year, and fur traders soon followed that incursion into the region. Traders representing the British Hudson Bay Company and the Canadian North West Company were especially interested in the bountiful supply of beaver and had little interest in the agricultural potential of the region. The early contacts between the Tribes and the white culture were initially economic transactions. The Tribes initially viewed the goods and supplies that traders and trappers offered as a welcome addition to their already thriving economy. Fort Nez Perce had been established in 1818 as a trading outpost at the confluence of the Walla Walla and Columbia River. It was renamed Fort Walla Walla in 1835.

The first explorers to the Columbia Basin were amazed by the amount of natural resources that were present and were eager to exploit them. The Northwest Fur employees eventually abided by the rules set down by the Indians mostly because they recognized the level of control the Indians exerted over their neighbors, and they recognized that open access to that land was essential for their business purpose. Tariffs were levied against the trading post for incoming and outgoing goods by the leaders of the bands whose forts occupied their lands. Fur companies often encouraged their men to marry women of the tribes to strengthen trade relationships with the Indian people.

In 1836, the Protestant missionaries Dr. Marcus Whitman and Henry Spalding arrived at Fort Walla Walla. Whitman founded his mission near present-day Walla Walla, Washington. Spalding founded his mission at Lapwai, Idaho. In 1838, the Catholic priests, Fathers Blanchet and Modesta Demers, arrived at Fort Walla Walla to establish Catholic missions. One was established near Walla Walla and, in 1847, another was established along the Umatilla River, near present-day Pendleton.

Until that time, life for European-Americans in the region was extremely difficult. Only fur traders and missionaries were hardy enough to make their way into the interior. But communications from explorers, fur traders and missionaries aroused the interest of those who still lived in the eastern part of the continent. The first wagon train entered the Oregon Country in 1843. It was led by Marcus Whitman. The Oregon Trail is described in the following section of this chapter. Tribes on the Columbia Plateau were protective of their sovereignty. With the great influx of settlers, miners, soldiers and cattlemen, the tribes began taking actions to rid themselves of the intruders. The military strength of the Tribes caused the United States to begin meeting with them to negotiate and sign treaties in an attempt to avoid further violence.

The primary purpose of the Treaty process was to establish peace by removing Indians from the land and to make way for industry and settlers. The unstable situation in eastern Oregon was the product of the 1850 Oregon Donation Land Act. Emigrants were given land as an incentive to move out west. By 1854, Governor Joel Palmer of Oregon had convinced the Indian Department that no further settlements were to be established east of the Cascades until the Indians there could be moved to reservations. Congress authorized negotiation of treaties in order to purchase the Indian lands, and establish a reservation for Indians.

On May 29, 1855, a Council was convened near present-day Walla Walla to discuss the situation. The Treaty of June 9, 1855 between the United States and members of the Walla, Cayuse and Umatilla tribes was signed, creating the Umatilla Indian Reservation, Yakama Indian Reservation, and Nez Perce Reservations. The Cayuse, Walla Walla and Umatilla Tribes ceded 6.4 million acres and reserved 510,000 acres on which to live. The Umatilla Indian Reservation was established along the western foothills of the Blue Mountains by the Treaty of Walla Walla in 1855. It included rangeland on the plateau as well as rangeland and forests in the mountains. The native people also reserved rights for fishing, hunting, gathering foods and medicines, and pasturing livestock on non-reservation lands. The Federal Government forced the Indians onto the Umatilla Reservation and the ceded Indian territories were declared public domain and were auctioned at public sale, usually to land speculators and the railroads. Many settlers had already moved into the Walla Walla Valley and conflicts between the Indians and non-Indians became common.

The settlers quickly discovered that Indian lands were capable of producing wheat, and the mountains were good for livestock grazing. Roads and trails utilized by the non-Indians were constantly encroaching on reservation lands. Public meetings were held throughout the region during the late 1860's, with the intent of removing the Indians from the Umatilla Reservation.

The U.S. Government had agreed in the Treaty to move the Oregon Trail south of the Reservation to prevent problems, but that never took place. The Trail continued to bisect the Reservation. During the official survey of Reservation boundaries, the original Treaty that encompassed 510,000 acres was reduced to 245,000 acres, or approximately half of the land area reserved by Treaty. As a result, on continued pressure from non-Indians, the U.S. Congress enacted legislation in the late 1800s that continued to reduce the size of the Umatilla Reservation. The legislation created land allotments for the individual tribal members at that time, then proclaimed the remaining acres as surplus and opened those acres for settlement by non-Indians. The Dawes Allotment Act of 1887 made way for the sale of "surplus" Indian allotments, with about 100,000 acres on the Umatilla Indian Reservation being allotted to non-Indians. The goal was to intermix non-Indians with tribal members to ‘acculturate’ the tribal members. Most of the allotted land was ultimately used for producing wheat and livestock. Approximately 30,000 acres were put up for sale. The town of Pendleton was allocated 640 acres of the Reservation, and the railroad was also constructed through the middle of the Reservation. By direction of the Secretary of Interior, an Indian Agent arbitrarily drew a line and removed the southern reservation. As a result, the Umatilla Reservation is now 158,000 acres, of which only 52 percent is in Indian ownership. The lands of the ‘Reservation’ are a checkerboard pattern of ownership in which non-Indians own nearly half the land and many of them reside within the current boundaries of the Confederated Tribes of the Umatilla Indian Reservation (CTUIR).

Allotment acts, incentives for railroads, miners, ranchers, and settlers led to increased pressure on lands significant to the Tribes. By 1900, the status of the Tribes had been reduced from relative wealth and well-being to poverty. Nevertheless, as will be described in Chapter 3, the Indian people had a significant influence on the establishment of the Pendleton Station, which is located immediately adjacent to a border of the Reservation. Today, the stature of these native people has been partially restored to wealth and well-being. The Reservation now rivals and often surpasses the City of Pendleton with respect to economic development and governance. Much has changed that is beyond the scope of this chapter. This section is concluded simply by stating that the CTUIR now operates a Tribal Farm Enterprise that is responsible for farming and improving 11,927 acres of land owned or leased by the Tribe, by some individuals, and by the Bureau of Indian Affairs. CTUIR actively buys 'non-Indian' land whenever possible to reduce the impact of the checkerboard-like ownership pattern. In 2017, the CTUIR farming operation included 3,255 acres of wheat, 3,745 acres of summer fallow, 152 acres of green peas, 4,463 acres of Conservation Reserve Program grassland, 49 acres of hay, and 263 other acres. The farming operation is equipped with the latest agricultural equipment and innovative technologies, and is directed by a professional farm manager.

The Counties

The Oregon Territory was formally established by treaty between the United States and England in 1848 (Anon. 2017c). The Territory included all of present-day Oregon, Washington, Idaho, and parts of Montana and Wyoming. When Washington Territory was established in 1853, lands in present-day Washington and Idaho, and parts of present-day Montana and Wyoming were ceded from Oregon Territory, which then became constrained into the boundaries of present-day Oregon. In 1854, the Oregon Territorial government established Wasco County (Anon. 2017e). That county became the largest county in the United States (Anon., 2017f), encompassing all of the Oregon Territory east of the crest of the Cascade Mountains; 130,000 square miles.

Oregon became elevated to the status of statehood in 1859. Discovery of gold in eastern Oregon and southwest Idaho created a gold rush from 1862 to 1868. The great influx of miners led to the development of numerous mining towns and the necessity for additional food and supplies in those remote towns. Ranchers and herders moved into the area and began producing beef and wool. Large amounts of supplies were moved by riverboat up the Columbia River to a burgeoning city named Umatilla Landing, at the confluence of the Umatilla and Columbia rivers. The supplies were then loaded onto pack animals or freight wagons for transport to the mining towns.

The increase in population at the beginning of the gold rush led to a cleaving of the original Wasco County. In 1862, that county was split into three large counties, establishing boundaries for 'new' Wasco, Umatilla and Baker counties. The new Wasco County retained all land from the top of the Cascades eastward to a north-south line from the point where Willow Creek joins the Columbia River, midway between current-day Arlington and Boardman. The segment of land between Wasco County and the crest of the Blue Mountains became Umatilla County, from the Columbia River/46th Parallel at the north to the Nevada border at the south. Baker County became a third north-south segment of eastern Oregon land between the crest of the Blue Mountains and the Snake River. The gold industry led to further division of Umatilla County in 1864, forming a new Umatilla County and Grant County. Further political and social pressures led to establishment of Lake County in 1874. The eastern Oregon counties were repeatedly cleaved into smaller governance units as population density increased in response to the arrival of the transcontinental railway during 1881. Establishment of Crook County occurred in 1882, Gilliam and Morrow counties in 1885, Harney and Sherman Counties in 1889, and Hood River County in 1908 (Anon., 2017g). The large north-south original Baker County also became progressively divided into Union, Wallowa, Baker and Malheur counties.

Present-day Sherman County did not become established until quite late, in 1889 (Anon. 2017d), only two decades before the Sherman Station was established. All present-day counties in eastern Oregon were established by 1916, two decades before the Pendleton Station was created.

Oregon Trail

The Preemption Act of 1841 encouraged settlement of 270 million acres of public land throughout the nation (Jackman, 1964). Settlers could acquire land for little or no cost. The Act also allowed the Federal government to grant 'pre-emption rights' to individuals who were already living on federal lands, and commonly referred to as 'squatters.' The squatters were allowed to purchase up to 160 acres of land for a price not less than $1.25 per acre. Individuals qualified for this acquisition if they were a head of household, a single man over age 21 or a widow, a citizen or an immigrant intending to become naturalized, and a resident of the land for a minimum of 14 months. The claimant did not need to have a title to the land.

From 1943 to 1949, more than 12,000 immigrants passed through the region following paths collectively called the Oregon Trail (CTUIR, 2017). Their route took them from the Grande Ronde Valley, across the Blue Mountains, and into the area of present-day Umatilla County. After 2,000 miles and six months of travel, the immigrants and their livestock were often weary and hungry. Nevertheless, the immigrants considered present-day Umatilla County as a forlorn, formidable, and wild place. The first wave of 875 immigrants, led by Marcus Whitman, in 1843, brought along 1,300 head of cattle. Once reaching the Umatilla River, they turned north to Whitman's Mission, established in 1836 near present-day Walla Walla. Another 1,200 settlers followed the Oregon Trail in 1844, and the number swelled to 3,000 in 1845 (CTUIR, 2017). Among the essential cargo in every wagon was a supply of wheat to be planted to establish a personal supply of flour at the place of settlement.

While the Whitman Mission was an important way station for Oregon Trail emigrants, none of them apparently expressed any interest in settling into the region even though they recorded the rich agricultural potential in the region. Most immigrants stopped at the Mission only to buy provisions, make repairs, and obtain medical services if needed. Most stopped for only a few days of rest but some overwintered at the Mission before continuing their trek to the west. The mission was also a haven for Hudson's Bay trappers, mountain men, explorers, and the native people. Most immigrants continued west in their wagons but some built rafts or hired boats to travel down the Columbia River. They departed from Fort Nez Perce, located at the confluence of the Walla Walla River and the Columbia River. The Whitman Mission remained in operation until November 1847, when Marcus and Narcissa Whitman, and 11 others, were killed during a period of unrest following a measles epidemic at the Mission. After the mission was closed the trail route was altered so that it headed almost due west after crossing the Blue Mountains. Pioneer journals from the Oregon Trail mention the wealth of the land and their trade of cattle, clothing, blankets, and utility items with the Native Americans. In return, the immigrants received horses, fish and vegetables. The journal of Absalom B. Harden, in 1847, stated "*...we are now traveling down the Umtillo river the indians hear has a great maney horses very fatt and the best I Ever Saw in my life they are very Rich som indians has from 50 to 100 horse and cattle in propostion they raise plenty of Corn and potaters and peas pumpkins squashes cabeges &c. this Countery is very fertile...*" (CTUIR, 2017). The Oregon Trail went through present-day Pendleton, at which point it crossed the Umatilla River. The trail then followed a path roughly parallel to present-day Interstate 84.

Nielson (1990) wrote "*After 1843, large numbers of immigrants used the Oregon Trail across Northeastern Oregon on their way to the Willamette Valley. They paid little attention to the dry country east of the Cascade Mountains as they hurried to the lush timbered land west of the mountains. Only in later years did homesteaders return to [present-day] Umatilla, Morrow, Gilliam, Sherman, Wheeler, and Grant Counties to raise cattle, sheep, or wheat. Thus, much of Northeastern Oregon was the last part of Oregon to be settled. Most of the homesteaders did not arrive until the 1870s and 1880s*."

The emigrants entered present-day Sherman County by crossing the John Day River at a place named McDonald's Ford (Franzwa, 1990). But again, apparently none of the immigrants expressed any interest in settling the region. None stopped for more than a few days' rest. During the mid-1840s, a deeply rutted trail crossed Sherman County using a near-direct route passing through Spanish Hollow (near present-day Wasco) and exiting the plateau at the base of what is now known as Fulton's Canyon, just east of where immigrants crossed the Deschutes River, enroute to The Dalles.

Giles French (1958) wrote "*Of the thousands who drove their wagons across Sherman County in the 1840s and 1850s not one stopped for more than a few days' rest. Not a single family pulled out of a wagon train to settle, though the grass was good and the springs sweet with fresh water. The vision of the green valley of the Willamette with its tall firs and meadows was in their eyes, and they pressed on*."

In 1842, the overland portion of the Oregon Trail ended at The Dalles. There was no way to move a wagon further west without building log rafts upon which to float the wagons and animals down the Columbia River. In 1845, Samuel Barlow marked a trail across the Cascade Mountains and into the Willamette Valley. Immigrants who chose the overland crossing traveled south from The Dalles on the Barlow Road, which roughly followed the route of present-day U.S. Route 197. They moved south to present-day Tygh Valley before turning west to cross the Barlow Pass at present-day Government Camp, just south of Mt. Hood. Soon thereafter, a shortcut was made to reduce the distance from McDonald's Ford to Tygh Valley. The shortcut went through what is now Grass Valley and crossed the Deschutes River near the present-day Sherar's Bridge, along State Route 216.

The Donation Land Claim Act of 1850 also encouraged residents of the Oregon Territory, in its initial form that included all or parts of five present-day states, to claim 320 or 640 acres of land for free between 1850 and 1854. The remaining land would become available for purchase at a cost of $1.25 per acre until the law expired in 1855. This helped stimulate the 'back migration' of recent immigrants to the Willamette Valley to seek larger holdings in the sparsely populated lands east of the Cascade Mountains. Nevertheless, there was little interest in this offering in the area of present-day Sherman County and Umatilla County.

Early European Settlers in Sherman County

John C. Fremont was apparently the first to recognize the agricultural capabilities in present-day Sherman County. Fremont explored the region in 1843 as an employee of the U.S. Topographical Corps. His diary reported that the area was "*a fertile, hilly country, covered ... with good green grass*." However, there was no settlement of present-day Sherman County until 1860 (French, 1958), even though one of the first roads in northeast Oregon approximately followed the Oregon Trail across the county (Nielson, 1990). The road connected The Dalles to the west with Umatilla and Walla Walla to the east. Bridges had been constructed across both the John Day and Deschutes Rivers. Pack trains enroute to the gold fields near John Day were using the road by about 1851. Soon thereafter, the road was being used by freight wagons and stages. Scheduled stages were operating on the road by about 1858. A telegraph line also followed the road during those early years. The first settler established and managed a stage stop on the road between the rivers (French, 1958). The horses were grazed on the abundant bunchgrass growing near the stage stop. Soon, grass hay also began to be mowed and hauled from nearby meadows. French reported that little official record exists for the earliest settlements. "*These early stockmen just moved in with their herds of horses and cattle, built a corral near a good spring, put up a little cabin and stayed until the grass was eaten down and moved on. Few remained long enough to be called permanent*." French continues with the names, locations and circumstances of the earliest somewhat-permanent settlers during the 1860s and 1870s. Yet, there were not many settlers who were interested in owning land during those early years (French, 1958) because those with cattle, horses or sheep could graze them on public lands without charge or conflict. The area first became thinly populated by people who made their living from travelers, by operating inns, stables, ferries and bridges. Few owned any land, and the stockmen moved on whenever the supply of grasses became too limiting for their animals.

The Homestead Act of 1862 liberalized the offer of land through the Donation Land Claim Act of 1850 by including any adult who had never taken up arms against the United States, including native-born men, and women or immigrants who had applied for citizenship (Anon., 2017b). The initial offering was for 160 acres of land. The claimant was required to file an application, improve the land, usually by building a dwelling, file for a deed of title, and reside on the land for five years. Alternatively, the claimant could directly purchase the land for a fee of $1.25 per acre.

Nielson (1990) wrote "*Most of the homesteaders did not arrive until the 1870s and 1880s*." During that short time interval, immigrants from throughout the United States and Europe arrived by the thousands. French (1958) wrote that "*They filled the land on Sherman hills in five years, plowed the grass that had sustained the stockmen's horses and cattle, built homes, started schools, established churches, made roads and fenced the rolling prairie, changing forever a way of life that has existed for forty years*. … *It was a movement similar to that which sent the wagon trains across the prairies to the Willamette Valley forty years before*." The movement was prompted by the promise of railroads that could move products to markets. The railroad along the Columbia River was constructed across the land between the John Day and Deschutes Rivers during 1881. In accordance with the Homestead Act of 1862, land became available to assist with construction of schools and roads. Nevertheless, many newcomers pre-empted these opportunities simply by just moving onto land and using it, as squatters. They had the support of laws to acquire "their" land whenever political pressures became great enough. The first government survey of Sherman County occurred during 1861 (French, 1958). All of the area of present day Sherman County had been surveyed by 1884, five years before the County was formally separated from the eastern side of what was then Wasco County.

Stockmen of that time had a steady market for supplying horses for farmers in the Willamette Valley. Cattle also were being driven to good markets in the mid-west. Since the new immigrants and emerging farmers in Sherman County provided additional markets, French (1958) reports that "*There is little evidence* *that the stockmen worried much about it. They could not imagine a world fenced into little fields and the waving grass turned under as fertilizer for sown crops. In their hearts they knew that settlement would result in failure*." However, the new farmers did succeed in dissecting the land and turning the sod. At first it was to produce a few acres of hay and a home garden, and then, with time, more acreages on which to produce grain. In a very short period of time the farmers had occupied the great amount of land that was able to be cultivated, all at the expense of the stockmen. French (1958) concluded that "*Surely no place in the west was settled more quickly nor by citizens with a greater range of nativity*." He goes on to quote George Doyle, who stated that "*The amount of land in cultivation in 1882 would not have exceeded 1000 acres, being in patches of from ten to twenty acres. The ground cut could not have been over 500 acres. The only 26 inch thresher run by horse-power was owned by … and was the first in the country. … There was not a bushel sold outside the county, it all being needed for seed and feed for the winter*." Three years later, Sherman County produced 1,654,210 bushels of wheat (French, 1958; quoting from the '*History of Central Oregon*.'). The stage lines were closed as the railroads became operational. "*Towns sprung up where there were not even postoffices five years before; there were well attended schools where the only young had been calves and colts; churches existed where the only worship had been of bountiful nature; there were roads where only trails had been*." (French, 1958).

The Homestead Act was amended by the Enlarged Homestead Act in 1909, which doubled the allotted acreage to 320 acres. That legislation occurred during the same year that the Sherman Station was being established. Another amendment, the Stock-Raising Homestead Act, passed in 1916, increased the allotted acreage to 640 acres.

Early European Settlers in Umatilla County

The first settlement of any kind in present-day Umatilla County was the Catholic Mission established near the Umatilla River on November 27, 1847, two days before the uprising at the Whitman Mission. The uprising disrupted the ability of the mission founders to conduct their work, and they abandoned the property in 1848. The mission site was destroyed, ending the first settlement in the area. Several years later the first actual settlers started arriving in the area. They included new immigrants and retired Hudson Bay Company French. They selected choice sites in the valleys of the Walla Walla River, Tucannon River, Touchet Creek and Mill Creek, all of which are in present-day Washington.

Dr. William McKay was the first true settler in the region of present-day Umatilla County (UCGH, 2017). In 1851, he located on the Umatilla River, near the confluence with McKay Creek. Although he was born in Oregon and schooled in New York, he was considered by the Cayuse people to be a Hudson Bay man due to their fondness for his father. Also in 1851, an Indian agency was established along the Umatilla River at the site of present-day Echo. The station was known as "Utilla." The McKay property and the Utilla Agency were the only settlements in the region when, in 1855, the Indian war drove all immigrants except the Hudson's Bay French settlers from the region east of the Cascades. McKay's standing with the Cayuse probably saved his life, as he was unharmed but was instructed to leave the area. His property and the Utilla Agency were both destroyed, which ended the second settlement of present-day Umatilla County. After the two-year war ended, a few of the earlier immigrants returned to the region, again mostly to the Walla Walla area where the Fort Walla Walla military post was established.

In 1857, settlers by the names of Arnold and Whitney settled on adjacent properties at the confluence of Birch Creek and the Umatilla River, a few miles downstream from present-day Pendleton. Other settlers returned to the old agency area near present-day Echo, and to the point where The Dalles to Walla Walla road crossed the Umatilla River, 1.5-miles downstream from Pendleton. At that location a saloon was also constructed and it became known as Marshall's Station (McArthur, 1992), and was named as the first interim county seat when Umatilla County was established in 1862. During 1859 and 1860 there were several additional settlers that became established in the area of present-day Milton-Freewater. Most were not family men and did not become permanent residents. Those and the Hudson's Bay French, with their Indian wives, were the residents of present-day Umatilla County in 1860 (UCGH, 2017).

After gold was discovered in eastern Oregon in 1861, homesteaders followed miners into the new land. The production of wheat in eastern Oregon was stimulated by development of markets caused by the development of new towns during the gold rushes to the rivers of John Day, Burnt River, Powder River and Eagle Creek. More settlers came to occupy choice locations along the rivers, and hotels or stations became established along the travel routes to the mining district. Thousands of cattle were driven into the region to graze on the lush bunch grass prairie. In 1862, there was still no real town in Umatilla County other than the mining camps on the John Day River. The rapid increase in populations demanded a supply of wheat in cities which were springing up, such as Canyon City, Granite, Auburn and Silver City (Brumfeld, 1968). With the need to transport supplies to the mining district and to move gold down the Columbia River, the town of Umatilla Landing sprang up at the confluence of the Umatilla and Columbia rivers. Umatilla Landing became a chief shipping point for a wide area, and was the first 'permanent' county seat as it was the only prosperous and thriving settlement in the region. Stagecoaches made connections with the riverboats. Supplies and equipment were shipped by pack trains or large freight wagons to the John Day mines, or east to Auburn and Boise City. Millions of dollars in gold were shipped down the Columbia River to the Pacific Ocean and then onward to San Francisco.

As described earlier, the Homestead Act of 1862 allowed settlers to establish ownership of 160 acres either through direct purchase or through occupation and improvement of the land over a five-year period. The Homestead Act also provided land for construction of schools and roads. Thousands of immigrants began to arrive, prompted by the promise of railroads that could move products to markets.

The first true farming settlers in present-day Umatilla County built their homes near Weston during the early 1860s. Tom Lieuallen settled at that location in 1862, and Andrew Kilgore settled an adjacent property during 1863. These early settlers will be discussed again in the following section on 'Wheat.'

The prosperity of Umatilla Landing lasted for only about five years before the mining trade dwindled. By 1868 the prosperity had shifted to Pendleton from Umatilla Landing. The population and prosperity of Pendleton was growing rapidly in response to the discovery that grain crops were extremely productive in that region. Thousands of acres of land were already being used to produce wheat along the foothills of the Blue Mountains. Barley was very productive in areas that were too dry to produce good crops of wheat. The county seat was moved to Pendleton in 1869.

The parcels of present-day Pendleton were originally known as Marshall Station and Swift's Station, or Middletown. The settlements were platted as Pendleton in late 1868, and it was incorporated as a city in 1880. The first census of Umatilla County, in 1870, counted 2,916 inhabitants. It increased with each successive decade until about 1920; with populations of 9,607 in 1880, 13,381 in 1890, 18,049 in 1900, 20,309 in 1910, and 25,946 in 1920. The population remained relatively static until 1940, at which time the population was 26,030. There was a large influx of new people during the 1940s, such that the population in 1950 was 41,703. The population today is about 76,000 (UCH, 2017).

Wheat Production

The first wheat to be brought into the Northwest appears to have been when the Hudson Bay Company imported one bushel each of wheat, oats, barley and corn in 1825 (Brumfeld, 1968). That shipment of seed was transported overland from Hayes River, at the mouth of the Hudson Bay, to Fort Vancouver. The grains were multiplied each year until, by 1828, the Company was able to suspend further shipment of flour from England to supply the needs in the Oregon Territory.

Wheat production was established in the Willamette Valley prior to 1836. A colony of former French-Canadian fur trappers began to colonize the French Prairie area near present-day St. Paul, Oregon beginning in 1829. The retired trappers married women of Native American heritage. They grew wheat as one of the subsistence crops, and the first flour mill in the Valley was constructed on the French Prairie during 1834 (Jackman, 1959). On March 22, 1836, the colony sent a petition to the Bishop of Juliopeles, near present-day Winnepeg, Manitoba, to request that priests be sent to minister to their religious needs at "Willammeth." In that letter they stated "*the farms are All in a very thriving state and produces fine Crops… The Country is setteling slowley and oure Children are Learning very fast… We have sent you a List of the families that Are at present in the settelment.*" An accounting of farms in the colony during 1838 was published by Lenzen (2017). That tabulation shows the presence of more than 20 families with nearly 50 children. The colony included at least 30 houses, 600 tilled acres, 150 horses, and 400 hogs. They produced about 7,500 bushels of wheat on their tilled fields during 1838. The first wheat exported from the West Coast may have been a shipment sold by the French Prairie settlers during 1839. At that time, 5,000 bushels of wheat was produced and 3,000 bushels of it was sold to colonists at Kamchatka, Russia (Jackman, 1959). By 1843, when the first Oregon Trail immigrants arrived in the Willamette Valley, the colony consisted of about 100 families that already occupied much of the best land north of present-day Salem (http://friendsoffrenchprairie.org/area-history.html).

Production quickly expanded throughout the Valley and became common in that area by the mid-1840s (Brumfeld, 1968). Nearly all towns in the Willamette Valley were developed because they were close to waterways that could drive flour mills (Jackman, 1959). Small commercial wheat crops were also being grown as early as 1839 at the St. Francis Xavier's Cowlitz Indian Mission, near present-day Toledo, Washington (Scheuerman and McGregor, 2013).

During the earliest years, the ripe grain was cut with a scythe and cradle, and the sheaf bundles were stood upright in shocks. Grain was threshed by hand with flails made of thorn, yew or other tough wood. Later, grain began to be threshed by leading horses in a circle around a hard threshing floor, to tramp the grain from the stalks. Before hand-powered fans became available in the late 1940s the workers waited for a stiff wind during which the they threw the straw five or six feet upward into the wind to separate the straw and chaff from the kernels of grain. Wheat was used for food and animal feed, and any surplus was shipped to Alaska, which was at that time a part of Russia. An oxen-driven grist mill was constructed as the first commercial flour mill in Vancouver during 1930 (Brumfeld, 1968). A water-driven mill was built in Champoeg during 1834, becoming the first mill in Oregon (Brumfeld, 1968). By 1844 there were four mills being operated in Oregon City.

East of the Cascade Mountains, Marcus Whitman, at Waiilatpu, near present-day Walla Walla, began growing wheat in 1837 and built the first mill in eastern Washington in 1840. It was a primitive water-driven mill. Wheat was first produced commercially in the Walla Walla area during the 1860s and, by 1864, there were five flour mills operating in the Walla Walla area.

By 1867 there was a surplus of wheat being stored in the Walla Walla area because there was insufficient local consumption and it was too costly to ship bulky products elsewhere using the then-current modes of transport. Moving wheat by wagon could sometimes be more expensive than income received from that product. By the mid-1870s the marketing problem became partially resolved by extensions of railroads and construction of flumes down which wheat could be sent to ports along the Snake River (Brumfeld, 1968). Larger-scale commercial production then expanded northeasterly to present-day Dayton, Washington in the 1870s, and into the Palouse region of Washington during the 1880s (McGregor, 1982; Scheuerman and McGregor, 2013).

Immigrants arriving in the Willamette Valley in 1867 found the best lands had already been claimed. By 1870, the Valley became too crowded and too conservative for the restless immigrants. Some, like Michael Schultheis, reversed their route in 1873 to claim land in the Walla Walla Valley and, two years later, moved onward to the Union Flat Creek area near present-day Uniontown, in Whitman County, Washington.

Wheat production then pushed westward into more arid regions, and southward into the area of present-day Umatilla County, Oregon (McGregor, 1982). The first wheat crop in eastern Oregon was a three-acre field grown in the early 1860s near the present-day town of Weston, in Umatilla County (Brumfeld, 1968).

Among the Federal legislation signed in 1862 by President Lincoln was the Pacific Railway Bill to make possible the construction of the nation's first transcontinental railroad. Other influential bills that year included a bill creating the Department of Agriculture, the Homestead Act, and the Land-Grant College (Morrill) Act (Scheuerman and McGregor, 2013). Collectively, these legislative acts during 1862 were highly influential in the development of agriculture in the Pacific Northwest. The expansion of railroads and improved shipping on the Columbia River helped create the multimillion-dollar wheat industry in the early history of these counties (Garber, 1998). The railroad transported the farmers' crops but, as importantly, it brought to them the bulky machinery that made production of wheat increasingly more efficient. Massive combines drawn by up to 40 horses dramatically cut the time that it took to harvest crops (Hollands, 1956). Mechanical grain threshers therefore removed a bottleneck in wheat production.

The first commercial wheat in Umatilla County was apparently produced in 1864 (Parsons, 1902). A 3-acre field was grown near Weston by Andrew Kilgore. Barrett (1915) stated that Kilgore's small field of wheat "*was cut by hand with a cradle, and threshed by being tramped out with horses, cleaned with a fanning mill, taken to Walla Walla and ground into flour at the Isaacs mill*." At that time, in 1864, there were five flour mills operating in the Walla Walla area.

Corn was also produced near Weston in 1865 (Barrett, 1915). Twenty acres of sod were plowed and corn was planted using an ax to cut the sod, dropping the corn by hand, and covering it by using the heel of the farmer's boot. Over the next two decades other settlers also began to produce excellent crops of corn in that area.

Barrett (1915) also stated that "*In 1868 several of the settlers in the vicinity of Weston and living on Wildhorse* [Creek] *above the present town of Athena raised small fields of grain. That year the first* *threshing was done with a small horsepower, hand feed machine by William Courtney. He threshed grain for Andrew Kilgore, Henry Hales, James Lieuallen, Taylor Green, Thomas Linville, D.A. Richards and probably others. Some of this grain was cut by hand with a cradle, some cut with a mower and rake and some cut with a hand rake reaper*." By 1870 there were reports of 40 acre fields of wheat being planted in the Weston area. Again, the grain was cut by hand with cradles and threshed with flails. The settlement of eastern Oregon grew rapidly from about 1870. The new immigrants came mostly by wagon train, and mostly from the Willamette Valley, where choice land had already become expensive and of limited supply.

Barrett (1915), who lived in the Weston area at that time, stated that a small header was used in 1871 to cut and stack wheat, and the grain was then threshed by horse-power and hand-feed machines. Albaugh (1935) stated that the first header was used to harvest grain in the Athena area during 1872. During a harsh winter of 1874-1875, all wheat in the region, consisting of two fields, were purchased, cut, hauled by bob-sled to present-day Adams, and fed to sheep on J. F. Adams' stock ranch along Wildhorse Creek.

Many more farmers began to settle into eastern Umatilla County and flour mills were being constructed throughout the region during the 1870s and 1880s (Barrett, 1915). Mills were located at such places as Walla Walla, Milton, Pendleton, Echo, and on the Umatilla Indian Reservation. Most of the grain was initially used for local consumption because the nearest points for shipping wheat down the Columbia River were at either Wallula Landing or Umatilla Landing, each of which required a long and difficult haul by wagon. Nevertheless, wheat and wool were being shipped from those river ports to all parts of the world during the 1870s (UCHS, 1980).

Wheat was being shipped regularly from west coast terminals by the 1870s. Some have stated that the first major shipment of wheat overseas was on the little bark *Helen Angier*, which left Portland in 1868 for the 5-month journey to Liverpool, England (Scheuerman and McGregor, 2013). In 1870, another bark filled with wheat departed from Portland to New York, via a route around Cape Horn. Likewise, during that same year, a German ship carried wheat from Portland to China. While wheat was being exported earlier, it was the development of markets in the 1880s that transformed economic relations that still exist today (Scheuerman and McGregor, 2013). The manager of Portland Flouring Mills recognized the incredible economic opportunity and began constructing additional flour mills throughout Washington, in places like Tacoma, Spokane, Harrington and Odessa. He formed Pacific Elevator Company to handle bulk storage and delivery to his mills. He then established Puget Sound Warehouse Company to bring his network of grain handling facilities to 350 locations for shipping bulk wheat to England and flour to China. In 1890 he arranged for a Canadian diplomat to represent his interests in Hong Kong, and then hired the diplomat as his company's export manager. The Union Pacific Steamer Company began shipping bulk wheat between Portland and the Orient in 1889 (Scheuerman and McGregor, 2013). The Northern Pacific steamer shipping service began services between Tacoma and the Orient in 1890, and the Great Northern vessels facilitated bulk wheat exports between Seattle and Hong Kong in 1896. By 1895 the export markets for Pacific Northwest wheat had been permanently changed. Wheat became the most important crop of the region. For example, by 1900, these markets opened Portland to the handling of some 40 million bushels of wheat from eastern Washington alone.

Production of wheat throughout the region had been initially constrained by the cost and difficulty in marketing the grain (Brumfeld, 1968). Surplus wheat was produced for the local population and it was too expensive to barge it down the Columbia River or to haul it over the Barlow Road to markets. Some wheat trickled to markets by barge, portage, wagon, river boat, and mule back. French (1958) wrote that "*The only place to market grain* [from Sherman County] *was along the Columbia River. For nearly twenty years all the wheat sold for use other than seed or feed had to be hauled* [by wagon] *mile after weary mile, ten, twenty, or even fifty miles to the warehouses at Biggs, Grant or Rufus on the River. Some could make a trip a day; some little more than a trip a week*."

One hundred and fifty people lived in present-day Sherman County in 1880. Very little land in that area was cultivated at that time. Land that was cultivated was used to produce winter feed for the stage horses and saddle horses. But it was the early stockmen who became the first farmers in present-day Sherman County. Circumstances for these early settlers began to change when a strip of land six miles wide across Sherman County, previously deeded to the Dalles Military Road Company, was sold in 1876 to Edward Martin, a wholesale liquor dealer from San Francisco and Portland. In 1884, that land became the Eastern Oregon Land Company, incorporated in California with headquarters in San Francisco. Much chaos and conflict began in the 1880s as a result of the Secretary of Interior's acceptance of settler's land filings on land already granted and deeded to The Dalles Military Road Company and Eastern Oregon Land

Company. Angry settlers were ordered off their homesteads. However, by 1890, the population in present-day Sherman County had swelled to 1,800. The consternation over land ownership issues in that area continued until the last of the Eastern Oregon Land Company's land was sold in 1945.

Influence of Railroads on Wheat Production

Wheat production in eastern Oregon expanded rapidly during the mid- to late-1870s in response to a more efficient way to move the grain to markets. The Walla Walla and Columbia River Railroad was completed between Walla Walla and Wallula in 1875, which reduced the distance required to haul grain to the rail terminal, and then onward by rail to the shipping port on the Columbia River (Anon., 2017a; Magnuson, 2015). Access to markets was again improved when the rail line was extended southward to Blue Mountain Station in Oregon, near present-day Weston, in 1879 (Magnuson, 2015). Those early railways had wood rails and were of a narrow gauge. Wheat production in eastern Umatilla County rapidly became the dominant form of agriculture after the railroad was extended southward to Blue Mountain Station (McArthur, 1992). During the late-1870s the wheat also began to be produced in the lower-rainfall area between present-day Helix and Athena. Albaugh (1935) stated that the period from 1876 to 1878 "*marked the ending of the great livestock and range area of Umatilla County and the beginning of the future prosperous enterprise of grain growing*."

By 1880 the region was one of the leading wheat-producing areas in the West. Parsons (1902) stated that "*First and most important among the industries of Umatilla County is the raising of wheat*." While substantial amount of wheat was being produced at that time, Barrett (1915) stated that the 'main wheat belt' in Umatilla County did not become fully developed until after completion of the railroad between Pendleton and Blue Mountain Station, in 1884, and of the Hunt Road from Wallula to Athena and Pendleton, about 1887.

The Oregon Railway and Navigation Company (OR&N) was established in 1879 by merger of the Oregon Steam Navigation Company and the Oregon Steamship Company. The OR&N purchased the Walla Walla and Columbia River Railroad in 1881 and widened its tracks to standard gauge. In 1882, the OR&N extended to Wallula a track from The Dalles to Celilo, originally constructed to by-pass an unnavigable section of the Columbia River. The OR&N also purchased other sections of track to connect westward to Portland. A branch that connected Pendleton and Umatilla Landing was also completed in 1882. In 1884, the OR&N connected with the transcontinental Union Pacific line that had previously had an eastern terminus at Huntington, Oregon, thereby completing a full-service transcontinental railroad through Umatilla County (Anon, 2017a). Also in 1884, a railroad line had been constructed from Pendleton to Centerville, which later was renamed Athena (Magnuson, 2015). By 1887 the railroad had been extended from Blue Mountain Station to Centerville, thereby completing the rail line between Walla Walla and Pendleton.

By 1890, Umatilla County was producing 4.5 million bushels of wheat, most of it being shipped by railroad to Portland to be exported. At that time, the entire state of Oregon produced about 15 million bushels of wheat. Umatilla County was therefore producing nearly one-third of the entire crop for the state (Parsons, 1902). After the rail connection between Umatilla County and Portland was completed during 1893, much of the wheat was sent by railroad to Portland to be exported to nations throughout the world. By 1895 the export markets for Pacific Northwest wheat had been efficiently developed and wheat became the most important crop of the region. By 1897, Umatilla County had more than 200 miles of railroad and produced 44 percent of Oregon's wheat (Hollands, 1956). In that year, the 12 counties of eastern Oregon produced about 13 million bushels of wheat, out of a state total of 20 million bushels. Umatilla County produced 4.5 million bushels of that total. Parsons (1902) stated the Umatilla County was already the "*banner wheat producing county of the state*." He went on to also state that "*Thirty years ago not a bushel of wheat was raised in that entire empire* [Umatilla County], *although across the line near Walla Walla some 300 bushels of wheat were raised by Dr. Whitman at his mission in 1841*."

The OR&N purchased the Washington and Idaho Railroad in 1896, enlarging the OR&N as a regional railroad that was operating 1,143 miles of track from Portland to northeast Oregon, northeast Washington, and northern Idaho. The Union Pacific Railroad purchased a majority stake in the OR&N in 1898, at which time the OR&N became as subsidiary to the Union Pacific. Umatilla County had 212 miles of railroad in 1901 (Parsons, 1902). The Union Pacific formally absorbed the OR&N system in 1936. A 1933 map of Pendleton showed downtown terminals, depots, and switching yards for the Northern Pacific Railroad as well as the Union Pacific Railroad.

Production of wheat in present-day Sherman County occurred long after cultivated wheat was being grown in the western valleys and the higher-rainfall regions of eastern Oregon and Washington. As further east, the first farmers who planted wheat in Sherman County harvested relatively few acres for the grain. French (1958) reported that "*These first farmers had a problem of saving seed for another crop as there were no threshing machines. A small amount could be tramped out by horses and winnowed in the wind. Eaton tramped out some rye as early as 1875 and the following year he and Price threshed several bushels in the same manner. The Fulton's also threshed seed grain about the same time. James Fulton brought the first threshing machine into the county in 1878 when he hauled a small separator from Fifteenmile in Wasco County across Sherar's Bridge to thresh out a small crop of wheat he had grown. It was a one-horse power rig, small and ineffective*."

Completion of the transcontinental railroad through the Columbia River Gorge, in 1883, eliminated some of the hindrance to moving the grain from eastern Oregon and Washington to shipping terminals on the Pacific Ocean. Homesteaders began arriving in the present-day Sherman County area during the 1880s by steamboat, railroad, stage, and wagon. All were eager for land and farmers began to settle every quarter section (Anon. 2017d). The area quickly transitioned from stock grazing to farming as homesteaders built homes and began to plow the grass and to fence the prairie in order to qualify for government patents to their land. With the increase in population there was also a sentiment for independence of the Wasco County area lying east of the Deschutes River. Sherman County was created in 1889, and was expanded southward by another 18 miles into Wasco County during 1891.

An article in the *Moro Observer* in 1894 was the first indication of railroad construction into Sherman County (French, 1958). The Columbia Southern Railway began constructing a line from Spanish Hollow (present-day Biggs Junction) southward through present-day Sherman County during 1897 (Anon., 2017a; French, 1958). Rail stations constructed along the line included Wasco (in 1897), Moro (1899), Grass Valley and Kent (1900), and Shaniko (1901). In 1902 the railway was sold to the OR&N. In 1910 that company became part of the Union Pacific Railroad Company, who leased it to another of their subsidiaries, the Oregon-Washington Railroad and Navigation Company. The Columbia Southern Railroad's primary business had been shipping of wool from Shaniko to the Columbia River. But wheat was also a primary commodity for the railroad. French (1958) stated that in 1900 there were 31 warehouses for storage of up to 40,000 bushels of wheat along the Columbia Southern Railway. The grain was supplied by 53 threshing outfits and 19 combined harvesters, which collected about four million bushels from 206,465 tillable acres on 110 farms. The population of the County had surged to 3,479 people in 1900, which was about twice the population (1,792) that had been present in 1890. Wheat acreage and production increased greatly as farming, transportation and marketing practices matured. In 1900 about half of Oregon wheat production was west of the Cascade Mountains, whereas the proportion diminished to about 10 percent by the mid-1960s (Brumfeld, 1968). By 1900, Umatilla and Sherman counties ranked first and second, respectively, in Oregon wheat production (Hollands, 1956).

The 1901 assessment for Umatilla County indicated the presence of 320,959 acres of tillable land, on which was raised 1 percent of all wheat produced in the United States (Parsons, 1902). Of that total, about 90,000 acres of Umatilla Indian Reservation land was "*of the finest wheat land to be found in the world, a belt in which the wheat does not merely grow but luxuriates in crops of from 25 to 50 bushels to the acre*." The wheat in 1901 sold for an average price of 50 cents per bushel, producing income of about 2.5 million dollars for the farmers (Parsons, 1902). It was stated that this was more money than was taken from the gold mines in Oregon in a single year, even though the County had some very famous gold mines. Already at that time, some farmers controlled from 2,000 to 5,000 acres of land, using steam plows and harrows and combined steam harvesters, which reaped the grain, threshed it, and put it into sacks. A new $200,000 roller flour mill was installed at Byers Mill in Pendleton during 1901 (Parsons, 1902). The mill was capable of producing 1,000 barrels of flour each day, and had a 500,000 bushel storage capacity for wheat to be processed.

The Reclamation Act of 1902 created an irrigated farming infrastructure for the sandy sagebrush lands of northwestern Umatilla County. The town of Hermiston was incorporated in 1907, during the same year that the present-day Cold Springs Reservoir and the water distribution canals were being constructed. By 1908, the first water was being released into the ditches and the first crops of hay, potato, corn and other crops began to be produced.

The region continued to develop in response to the amendment of the Homestead Act in 1909, the year the Sherman Station was established. The Enlarged Homestead Act of 1909 increased the homestead acreage to 320 acres. Soon thereafter, that entitlement was again doubled by another amendment, the Stock-Raising Homestead Act of 1916. The peak population for Sherman County (4,242 people) occurred in 1910 before declining to less than 3,000 by 1930, and to less than 2,000 by 1990 (Anon., 2017d). As occurred throughout rural America, there were many closely-spaced communities during the early years. Most of those towns no longer exist. The most durable of the early communities in Sherman County include Moro (incorporated in 1899), Grass Valley (1901) and Wasco (1901).

Competition greatly reduced profitability for the Columbia Southern Railway in Sherman County. In 1911, a competing railway began operating along the Deschutes River to shorten the link between the Columbia River and Bend. The Columbia Southern Railway soon became nearly totally dependent on shipments of wheat from Sherman County. Market roads were also being improved and the Bonneville Dam with its navigational locks was completed in 1937. These innovations allowed further development of shipping terminals along the river, which facilitated greater opportunities to ship wheat to markets by barge as well as by rail and truck. The railway from Kent to Shaniko was abandoned in 1943. The Dalles Dam was completed in 1957, again increasing the efficiency and lower cost of shipping grain from the area by barge. The entire Columbia Southern Railway through Sherman County was abandoned in 1964.

Farming Methods and Equipment

The earliest settlers in the semi-arid regions plowed and planted their fields to spring wheat every year. That practice dissipated rapidly during the 1880s and by 1900 most farmers were producing winter wheat in rotation with a season of summer fallow to conserve soil moisture (Brumfeld, 1968). As with the production practices, farming and marketing practices also evolved rapidly as the wheat industry grew. Nearly all of the grain was sacked for transport to market prior to 1920. By the 1940s most farmers found it more economical to truck their wheat in bulk form (Due and French, 1979).

Mechanized equipment was introduced when enough acreage had been cultivated to make it necessary to cover more acres each day. A revolution in agricultural mechanization occurred at the same time railways were connecting wheat-producing regions with potential markets. Hand seeding or seed mechanically broadcast from the backs of wagon were replaced by seed drills that were rapidly advancing in technology and efficiency. Manual harvesting by use of scythes and cradles was largely replaced by horse-powered headers or binders by 1905. Whole plants were transported to a central area and stacked in preparation for threshing of the grain. Threshing was initially by horse power until portable steam engines were developed.

Steam engines began to be used to power stationary threshing machines in Umatilla County about 1878 (Albaugh, 1935). These engines had plenty of power to drive a belt but did not have sufficient traction power to pull implements. Most work on the farm therefore still required horses for power. Steckel and White (2012) considered agriculture before 1910 to be "*pre-tractor.*" They illustrated that horses or mules were increasingly replaced by tractors during the 1920s and 1930s, and these power sources became equal in the USA during the mid-1940s.

Albaugh (1935) indicated that the first combine harvester to be used in Umatilla County was used on the J. F. Temple farm northwest of Pendleton in 1888. The combine was manufactured by the Best Company, was pulled by 32 horses, cut a swath of 17 feet, was powered by a ground-driven bull wheel, and did not have a leveling device, resulting in substantial loss of grain on hillsides. This novel introduction caused many people from eastern Oregon and eastern Washington to witness the operation of that combine. However, the Temples did not purchase that first combine to be used in the County. After using it to cut and thresh about 1,500 acres, the Temples returned it to the manufacturer in California.

Horse-powered mobile headers were used to cut the wheat, which was then transported by conveyer into header boxes (wagons) to be taken to a stationary thresher. Additional combines manufactured by the Holt Manufacturing Company began to be used in about 1893 (Albaugh, 1935). The major transition from stationary threshers to mobile combine threshers occurred in Umatilla County during 1895 and 1896. The Holt combine was then used almost exclusively until 1903, when the Best combine was introduced and quickly became the choice among farmers. The mobile threshing and grain sacking machines were drawn by about 30 mules or horses.

A photo of a steam tractor pulling a combine thresher in Umatilla County during 1902 was shown in Garber (1998). However, most combines of that era were too cumbersome to be drawn on uneven terrain by the earliest farm tractors. Albaugh (1935) stated that at least four farmers were using the first steam traction engines to pull tillage equipment but not combines during 1904 and 1905. One of the most important improvements to combines was the introduction of leveling devices in about 1904. The transition to mobile threshing started to become more popular by about 1906. As described previously, gasoline-powered tractors were introduced in about 1907 and quickly gained popularity. However, Brumfeld (1968) displayed an image of a Pendleton-area farmer who was harvesting wheat with a horse-powered combine for the first time in 1911.

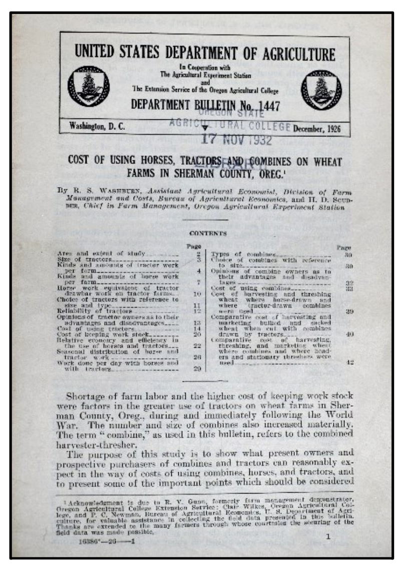
The first combines that cut and threshed grain in one operation in the field appeared on some larger farms in Sherman County by about 1906. The early combines were cumbersome and required the power of 18 to 40 horses, depending upon the weight of the combine and the steepness of slopes. While the required number of horses was high, the switch to mobile combines reduced the number of men required in the harvest operation by up to 80 percent, compared to the use of a stationary threshing machine. Images of these activities and the equipment are well illustrated and described in numerous books (Brumfeld, 1968; Garber, 1998; McGregor, 1982; Scheuerman and McGregor, 2013; and UCHS, 1980). The 150 man-hours of labor required to plant, cultivate and harvest an acre of wheat in 1840 was reduced to about 40 hours by 1890 (Scheuerman and McGregor, 2013). This form of harvesting with horse-drawn combines continued until about 1913, at which time some farmers began using huge steam-powered tractors to pull the combine.

Farmers transitioned through an intermixture of new and old systems. One modification was the switch from combines that were powered by a ground wheel to those that were motorized, but still pulled by horses because tractors were too unwieldy on the steep slopes of the region.

In 1910, the year in which the Sherman Station was established, the "Commercial Review" in Washington reported "*During the past season a 45 horsepower Caterpillar engine* [tractor] *was put to practical use … for the first time. The experiment proved so satisfactory that several others have followed the lead this spring, and have traded their 24 and 32 horse teams for Caterpillars*." (McGregor, 1982). By 1918 the use of gasoline-powered tractors had become common. A diesel-powered model was introduced in 1932. The cross-over point for which the number of tractors and of work horses and mules were equal in the USA did not occur until the mid-1940s (Steckel and White, 2012).

The first self-propelled Holt combine was used in the region during 1916, and another was being operated by a Tribal member on the Umatilla Indian Reservation in 1917 (UCHS, 1980). The East Oregonian newspaper, on June 8, 1917, reported that the "*High price of sacks and the prospective shortage of farm labor this summer are proving effective arguments for the bulk methods of handling grain and not a few farmers are already making plans to equip themselves to use this method. Quite a number of others are seriously considering the change from the more cumbersome and expensive sack method. The price of sacks has been steadily soaring until the sack bill for harvest will be a very considerable item. One farmer who has already made provisions to handle his grain in bulk estimates that he can equip his harvester, construct wooden bins and wagons at a cost of less than his sack bill would be. At the same time the change will enable him to dispense with three men on his machine and to store this grain as soon as he harvests it. The building of an elevator in this city has given an impetus to the bulk method*."

This revolution in agricultural mechanization occurred at the same time the railways were connecting wheat-producing regions with potential markets. An advertisement in the East Oregonian Newspaper, dated January 9, 1929, listed the names or companies (and their nearest town) of those that purchased Caterpillar tractors from the A.E. Page Machinery Company during the previous year. The advertisement listed nine who bought a model Twenty, 80 who bought a model Thirty, and 54 who bought a model Sixty. That company and others often made near-even trades of horse and mule teams for tractors. A salesman for one company estimated that he accepted 10,000 horses and mules as trade for Caterpillar tractors in the Walla Walla area alone during the Great Depression years of 1931-1937 (McGregor, 1982). The transition from horse-drawn combines became complete during the 1930s.


UNITED STATES DEPARTMENT OF AGRICULTURE
In Cooperation with
The Agricultural Experiment Station
and
The Extension Service of the Oregon Agricultural College
DEPARTMENT BULLETIN No. 1447
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COST OF USING HORSES, TRACTORS AND COMBINES ON WHEAT FARMS IN SHERMAN COUNTY, OREG.[1]

By R. S. Washburn, *Assistant Agricultural Economist, Division of Farm Management and Costs, Bureau of Agricultural Economics*, and H. D. Scudder, *Chief in Farm Management, Oregon Agricultural Experiment Station*

CONTENTS

Shortage of farm labor and the higher cost of keeping work stock were factors in the greater use of tractors on wheat farms in Sherman County, Oreg., during and immediately following the World War. The number and size of combines also increased materially. The term "combine," as used in this bulletin, refers to the combined harvester-thresher.

The purpose of this study is to show what present owners and prospective purchasers of combines and tractors can reasonably expect in the way of costs of using combines, horses, and tractors, and to present some of the important points which should be considered

[1] Acknowledgment is due to R. V. Gunn, formerly farm management demonstrator, Oregon Agricultural College Extension Service; Clair Wilkes, Oregon Agricultural College, and P. C. Newman, Bureau of Agricultural Economics, U. S. Department of Agriculture, for valuable assistance in collecting the field data presented in this bulletin. Thanks are extended to the many farmers through whose courtesies the securing of the field data was made possible.

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Figure 1-1. Bulletin describing economic decisions for using horses, tractors or both (1926)

Technological improvements accelerated rapidly during the industrial revolution. A 20-horsepower tractor could harrow 90 acres in a 10-hour day, which was three times the amount that horses could cover. A tractor could plow 28 acres, compared to four acres using a team of five horses. Seed drills pulled by tractor could cover three times the land covered by a horse-drawn team, and a second shift could work during the night to expedite the process. But during harvest, tractors were initially used to power the drive belts for the separating equipment. The initial combines were simply too cumbersome to be drawn by tractors of that era, particularly for the majority of farmers who grew wheat on uneven terrain. The transition to tractors became complete during the 1930s.

The deep-furrow drill was introduced into the drier regions in about 1927, which greatly increased the consistency of achieving acceptable stands during drier years and with earlier planting dates.


John Deere HZ deep-furrow seed drill and depressed furrows in cultivated fallow

Early Weeds and Diseases

The new farms in eastern Oregon and Washington did not have to contend with weeds or recognized diseases when they first broke the sod. There were apparently no weed seeds in the virgin sod. Russian thistle was first observed at scattered locations along the railways in eastern Washington during 1897 (McGregor, 1982). Repeated attempts to eradicate this noxious, invasive weed by agents on horseback and by foot were total failures. Other weeds then also began to invade wheat fields, including Jim Hill mustard, tarweed, Canada thistle, morning glory (field bindweed), wild oat, and China lettuce (McGregor, 1982). French (1958) stated that, for the Sherman County area, "*It was not until the Columbia Southern Railroad was built that weeds became the nuisance they were later. Weed seed from litter in stock cars was scattered along the right-of-way to grow and spread*." Likewise, farmers soon had similar problems following the purposeful introduction of the forage crop hairy vetch, a creeping legume, for the purpose of minimizing the depletion of nitrogen in soils. The vetch spread rapidly and soon became a serious pest that could not be eradicated from grain fields. Farmers increased the intensity of tillage in attempts to combat these weeds. Some farmers who had begun growing winter wheat reverted to planting spring wheat and burning the stubble in attempts to thwart the spread of these weeds.

The introduction of the wheat smut (common bunt) fungus during the 1890s introduced a new hazard into the use of the newly mechanized wheat harvest. In eastern Washington, a common question among farmers was "*Has your threshing machine exploded yet?*" This question reflected the very serious threat of explosions and fires which became commonplace when the highly explosive smut spores became ignited by hot machinery or sparks caused by cylinder teeth inside the threshing machines. During the late 1890s smut explosions destroyed a lot of machinery and started many fires in fields of mature wheat or of recently harvested stubble (Brumfeld, 1968; McGregor, 1982).

Improvement of Wheat Varieties

From the beginning of wheat production in the area, farmers were experimenting with different varieties and types of wheat to find those best suited to the soil and climate (Scheuerman and McGregor, 2013). New introductions during the 1880s included 'Big Club', also called 'Crookneck Club' or 'Walla Walla Club.' Big Club was a southern European soft yellow spring wheat introduced to western Washington by the Hudson's Bay Company as early as 1854 (Scheuerman and McGregor, 2013). Another important variety was 'Little Club,' a soft-white wheat from southern Europe that had been imported from California in 1859. Similarly, 'Red Fife' was a hardy, high-quality Ukrainian hard red bread wheat that had been brought to Oregon from the mid-west by early settlers, and became widely grown by the 1880s (Hall, 1959; Scheuerman and McGregor, 2013). Yet another important variety was 'Pacific Bluestem', a soft-white spring wheat which had been imported from Australia by a Walla Walla seed company in 1882. 'Goldcoin' was a spring variety being grown in Illinois and New York during the early 1800s and became distributed and grown as a soft-white winter wheat under the name 'Fortyfold' in Oregon during 1899. 'Marquis' (hard-red spring) and 'Hybrid 128' (soft-white winter) were also to become important varieties imported from southern Europe during the 1870s and 1880s (Scheuerman and McGregor, 2013). Other early wheat varieties included the spring wheats 'Red Russian' and 'Red Chaff' (French, 1958).

French (1958) stated that "*There was little science applied to agriculture in the eighties. Experiments toward finding better crops, better livestock, better methods had barely started. … A very little poor judgement eliminated a man quickly from the race for riches via the wheat farming route*." The crops were very poor during 1892 and 1893. Some farmers in Sherman County had no income at all during 1893. However, the 1894 crop was exceptionally productive and some estimates were that 2,250,000 bushels had been produced in Sherman County (French, 1958). In 1895 there were 82,000 acres of wheat harvested, for a yield of 1,617,790 bushels.

While the first wheat to be planted in the dry regions was spring wheat, it was soon discovered that varieties such as Bluestem and Fife would survive most winters and produce more grain, as well as spread the workload more evenly across the year (French, 1958). Nevertheless, these varieties were not truly winter hardy and it was often necessary for them to be re-planted when they failed to survive the winter. In 1906 the Eastern Oregon Land Company, in Sherman County, purchased six carloads of Turkey Red wheat from Kansas. Turkey Red was a hard-red winter wheat imported into Kansas in 1874 by Mennonite immigrants from the Crimea and Prussia. This variety had gained tremendous popularity in Kansas and was soon proven to be hardy enough to withstand winters in the Pacific Northwest. Turkey Red quickly became the leading variety and held that status when the Sherman Station was established in 1909. By 1930, when the Pendleton Station was being established, improved varieties were available from research that had been provided by scientists at the Sherman Station, the Lind Station, and Washington State College.

Wheat types or Market Classes

Spring wheat: planted during the spring; sensitive to cold winter temperature

Winter wheat: capable of surviving winter temperatures commonly experienced in an area; planted during the autumn; often produces more grain than spring wheat

Hard-red: a type of wheat with high protein and strong gluten; best suited for baking loaves of bread

Soft-white: a type of wheat with low protein and weak gluten; best suited for noodles, pastries, flat breads, cookies, and sponge cakes

Club wheat: a sub-class of soft-white wheat with short thick compact club-shaped spikes; often blended with other soft-white wheats to improve their flour properties

Science

In 1884, the scientist William Jasper Spillman was hired to teach agriculture and to conduct research at Washington State College. He became the first highly-renowned wheat geneticist in the inland Pacific Northwest. He was asked by wheat growers to help them increase productivity by developing varieties for individually distinct soil and climatic regions that were present across the Columbia Plateau. In 1901 he announced at a meeting in Washington, D.C. that he had confirmed and gained further understanding of the quantitative transmission of wheat traits from parental varieties to their hybrid offspring. His experiments were accepted as an independent rediscovery of Mendel's Law of Heredity, and he was thereafter credited as having a major role in the acceptance of Mendel's Law by scientists and agriculturalists. He strongly advocated for selective crop breeding based on regional conditions. Spillman moved from Pullman to Washington, D.C. in 1902 to begin work with the U.S. Department of Agriculture. His studies during the previous 17 years were oriented directly toward the needs of farmers in the various precipitation zones in Washington, which dynamically set the stage for low-rainfall cereal investigations that were initiated when the Sherman Station was established in 1909. This was particularly important because most of the initial wheat accessions at the Oregon Agricultural College were from experiment stations and seed suppliers in Indiana, Illinois, and Colorado, all of which receive significant amounts of rainfall during summer months when wheat is maturing (Scheuerman and McGregor, 2013).

Other important events in 'scientific agriculture' also had a strong influence on establishment of the Sherman Station. Two 'dryland' agricultural research stations in the western U.S. were established within a period of six years before the Sherman Station was established. The 'Nephi Sub-Station' was established in 1903 near Nephi, Utah and was administered by F. D. Farrell. Today the station is named the Nephi Dryland Research Farm and it is the oldest continuing dryland experiment station in North America. Four years later, in 1907, the Judith Basin Substation for Dry Land Agriculture was established on 80 acres of land near the town of Philbrook, Montana. Now named the Central Agricultural Research Center, it currently encompasses 480 acres of land near the present-day town of Mocassin, Montana. The first Superintendent was Ernest L. Adams but in 1909, John M. Stephens was an agronomist at that location and soon thereafter became the Superintendent of that facility. He was the brother of the soon-to-be Superintendent of the Sherman Station in Moro, Oregon.

French (1958) wrote that government policy affected farmers in Sherman County, from the first settler to the present day. He stated that "*… government programs have almost as much to do with possible profit as industry and skill at agriculture*." French also stated "*Farmers were independent in those days and were inclined to resent any interference from federal and state governments unless carefully presented. There was no opposition, although probably some scorn, when* [in 1899] *James Withycombe sent his Oregon Agricultural College men to Sherman County to try some experiments. The venture received no publicity or support from local sources, however. Later when farm trains* [traveling educational displays mounted in rail cars] *were sent to change the way of farming they were visited by good crowds of people, some of whom joked about learning to farm from a white collared professor*."

Withycombe was a diversified farmer in the Willamette Valley and, in 1898, without any training as a scientist, was appointed as a Professor of Agriculture at Oregon State College and the Vice-Director of the OAES. He soon became the Governor of Oregon. In 1899, shortly after being appointed at the College, he wrote a bulletin denouncing the practice of summer fallow in the dry regions of the State. Withycombe had witnessed a type of summer fallow widely practiced in the region and also in the mid-west. The so-called "dust mulch system" encouraged farmers to burn their stubble and till the fallow from six to 10 times a year in order to create "the dustiest, smoothest, cleanest, least lumpy, and least trashy field surface." Most growers followed that practice even though professors at Washington State College and Oregon State College issued warnings about destroying the soil in order to conserve moisture and to possibly mineralize some nitrogen (Scheuerman and McGregor, 2013). The scientists outlined a priority need to conserve organic matter and to prevent erosion. In Oregon, Withycombe stated "*In the eastern portion of the state, the question of the conservation of moisture, of the maintenance of a desirable physical condition of wheat producing land, of the replenishment of ranges with nutritious grasses, and of irrigation, demand the immediate and serious attention of the station. At the present time wheat is being successfully grown in this portion of the state upon arid and semi-arid land without irrigation; but the method employed in the preparation of the land, while eminently satisfactory to the farmer at present is, however, a temporary expedient only and will ultimately terminate disastrously to the productiveness of the soil. The objectionable method is the summer fallow. This system of farming reduces the humus content of the soil so as to render it less retentive to moisture*." French (1958) wrote "*That year* [in 1899] *Mr. Withycombe established four quarter-acre experimental plots on farms near Moro and grew Canadian Field peas and vetch. ... So important did he consider the problem that he recommended in the 1900 report that an effort be made to establish an experiment station in that region to make adequate research on the many problems of semi-arid farming*." That became the first public documentation of a concept that led to the establishment of the "*Eastern Oregon Dry-Farming Branch Experiment Station*," at Moro. But the process was not straight forward or rapid, even though the first such branch station was soon to be established at Union, in Union County, Oregon during 1901.

C. E. Bradley, of Oregon Agricultural College, collected soils from pairs of sites in Sherman County during 1909. One sample was taken from an area of virgin grassland and a nearby sample was taken from a field managed as a wheat-fallow rotation. Bradley compared the concentrations of nitrogen and carbon in the samples and published his results in what is thought to be the first scientific paper produced from research in Sherman County (Bradley, 1910). In that paper Bradley showed a trend for what he had anticipated; cultivated farming for about 30 years had reduced the amount of organic matter by about 25 percent, both in the surface soil and subsoil. He predicted an increasing magnitude of soil degradation in the future, which became one of the main determinants of initial experiments when the Sherman Station was established. Additional aspects of early studies on soil organic matter and the development of dryland farming systems throughout the Pacific Northwest are eloquently described by Schillinger and Papendick (2008).

Economic and ecological problems in Umatilla County were very similar to those that were studied under more arid conditions at the two dryland experiment stations that already existed in 1928, the Sherman Station and the dryland branch experiment station at Lind, in Adams County, Washington. The early experiments in Umatilla County were therefore directed by scientists at the Sherman Station, with additional tests being coordinated by or with scientists at Washington State College (Pullman), Oregon State College (Corvallis), and the branch station at Lind, Washington. However, it was inconvenient and inefficient for scientists at those locations to conduct field trials throughout eastern Oregon. Field trials at remote locations sometimes could not be done at the precise time when observations or measurements needed to be made. The two other experiment stations in the region, at Hermiston and at Union, focused on livestock and irrigated crops, and scientists at those locations were not well suited for conducting experiments on dryland wheat.

Residents of Umatilla County persuaded the USDA-BPI and Oregon State College to establish another dryland station near Pendleton. Development of new wheat and barley varieties at the Sherman Station, with off-station testing nurseries throughout northcentral and northeast Oregon, had already led to significant improvements in yield and grain quality, and in the control of weeds and diseases, including common bunt (stinking smut). Seventeen previous years of research at the Sherman Station had revealed procedures that gave greater efficiency to the methods and timing of tillage, and to methods and timing for planting wheat and barley. The crop rotation and cover crop experiments at the Sherman Station had already demonstrated that the cultivated winter wheat-summer fallow system was most profitable in the lower-rainfall region. Soil erosion was still problematic but was being reduced by the tillage systems identified prior to 1928. Further examination and refinement of these principles were necessary to improve the profitability of the bountiful crops already being produced under the higher-rainfall conditions that exist in Umatilla County. While many farmers in Umatilla County had already transitioned from horse-drawn equipment to tractors, that technological advancement would not be adopted for another decade at the new dryland experiment station in Umatilla County.

References:

Albaugh, J. E. 1935. History of Settlement and Agricultural Development of Umatilla County. Unpublished. 15 pages.

Anon. 2017a. History of Rail in Oregon. Wikipedia. https://en.wikipedia.org/wiki/Rail_transportation_in_Oregon

Anon. 2017b. *Columbia Southern Railway and Oregon-Washington Railroad and Navigation Company*. Wikipedia. https://en.wikipedia.org/wiki/ Columbia_Southern_Railway, and https://www.pnwc-nrhs.org/hs_or_n.html

Anon. 2017c. Oregon Railroad and Navigation Co. https://en.wikipedia.org/wiki/Oregon_Railroad_and_Navigation_Company

Anon. 2017d. *Homestead Acts*. Wikipedia. https://en.wikipedia.org/wiki/ Homestead_Acts

Anon. 2017e. *Oregon Territory*. Wikipedia. https://en.wikipedia.org/wiki/ Oregon_Territory

Anon. 2017g. *Sherman County*, Oregon. Wikipedia. http://en.wikipedia.org/wiki/ Sherman_County,_Oregon

Anon. 2017f. *Wasco County, Oregon*. Wikipedia. https://en.wikipedia.org/wiki/ Wasco_County,_Oregon

Barrett, C. A. 1915. Early farming in Umatilla County. Oregon Historical Quarterly Vol.16, pages 343-349. Umatilla County Historical Society, Pendleton, Oregon.

Bradley, C. E. 1910. Nitrogen and carbon in the virgin and fallowed soils of eastern Oregon. *Journal of Industrial Engineering and Chemistry* 2:138-139.

Brumfield, K. 1968. *This was Wheat Farming: A pictorial history of the farms and farmers of the Northwest who grow the Nation's bread*. Bonanza Books, New York. 191 pages.

[CTUIR] Confederated Tribes of the Umatilla Indian Reservation. 2017. History of CTUIR. Online at http://ctuir.org/history-culture/history-ctuir

Due, J. F., and G. French. 1979. Rails to the Mid-Columbia Wheatlands: the Columbia Southern and Great Southern Railroads and the Development of Sherman and Wasco Counties, Oregon. University Press of America. Lanham, MD. 297 pages.

Franzwa, G. M. 1990. *Maps of the Oregon Trail*. The Patrice Press, St. Louis, Missouri. 295 pages.

French, G. 1958. *The Golden Land: A History of Sherman County, Oregon*. Oregon Historical Society, Portland. 237 pages.

Garber, M. 1998. Umatilla County: The Early Years. Pediment Publishing, Portland, Oregon. 128 pages.

Hall, W. E. 1959. *History of Wheat Varieties in Sherman County*. Oregon Agr. Exp. Station Unpublished Mimeo. 3 pages.

Hollands, H. F. 1956. Pacific Northwest Wheat. Oregon Agr. Exp. Sta. Bulletin 556. 47 pages.

Jackman, E. R. 1959. Wheat – *Our No. 1 Crop Since Pioneer Days*. The Oregon Farmer, August 6, 1959. Pages 5 and 6.

Jackman, E. R. 1964. Uncle Sam is rich enough to give us all a farm. Pages 49-64. In: *The Oregon Desert* (E. R. Jackman and R. A. Long, eds.). Caxton Press, Caldwell, Idaho. 407 pages.

Karson, J. (editor). 2006. Wiyáx̣ayx̣t * As Days Go By * Wiyáakaaʔawn: Our History, Our Land, and Our People: The Cayuse, Umatilla, and Walla Walla. Tamástslikt Cultural Institute (Pendleton) and the Oregon Historical Society Press (Portland). 265 pages.

Lenzen, C. 2017. Settlers on French Prairie, Oregon Territory, in 1836-1838. Online at: http://www.lenzenresearch.com/STPaulpages/spfrprairie.html).

Nielsen, L. E. 1990. *Roads of Yesterday in Northeast Oregon*. Maverick Publications, Inc. Bend, Oregon. 143 pages.

Magnuson, A. C. 2015. The Blue Mountain Branch Line through the Wheat Belt. Online at http://craigmagnuson.com/bluemtn.htm

McArthur, L. A. 1992. *Oregon Geographic Names, Sixth Edition*. Oregon Historical Society Press, Portland. 957 pages.

McGregor, A. C. 1982. *Counting Sheep: From open range to agribusiness on the Columbia Plateau*. University of Washington Press, Seattle. 482 pages.

Parsons, C. W. 1902. An Illustrated History of Umatilla and Morrow Counties. W. H. Lever Publisher. 581 pages.

Scheuerman, R. D., and A. C. McGregor. 2013. *Harvest Heritage: Agricultural origins and heirloom crops of the Pacific Northwest*. Washington State University Press, Pullman. 186 pages.

Schillinger, W. F., and R. I. Papendick. 2008. Then and now: 125 years of dryland wheat farming in the Inland Pacific Northwest. Agronomy Journal 100 (Supplement):S166-S182. (Also published in 2009 as Washington State University Extension Manual EM004E. Pullman, Washington. 22 pages).

Steckel, R. H., and W. J. White. 2012. Engines of Growth: Farm Tractors and Twentieth-Century U.S. Economic Welfare. National Bureau of Economic Research Working Paper 17879. Cambridge, Massachusetts. Online at http://www.nber.org/papers/w17879

[UCGH] Umatilla County Genealogy and History. 2017. Oregon Genealogy and History: Umatilla County. Online at http://www.oregongenealogy.com/umatilla/earlyhistory.htm

[UCH] Umatilla County History. 2017. Oregon Historical County Records Guide. Online at http://arcweb.sos.state.or.us/pages/records/local/county/umatilla/hist.html

[UCHS] Umatilla County Historical Society. 1980. Umatilla County: A Backward Glance. E.O. Master Printers, Pendleton, Oregon. 270 pages.

Chapter 3 - Dryland Stations and Centers in Oregon

Reference to the 'dryland experiment stations and centers' refers specifically, in this book, to the research centers near Moro and Pendleton, Oregon. Other dryland agricultural research stations were also established in Oregon but have changed in focus over time, mostly through the advent of irrigated agriculture or livestock production in regions near stations such as at Hermiston, Union, Burns, Ontario, Madras and Klamath Falls. Only the Sherman Station and the Pendleton Station have remained continually focused on the production of field crops under non-irrigated low-precipitation conditions, which is the focus of this book.

While research at the Sherman and Pendleton Stations continued to follow their original objectives over time, the names of those stations changed as administrative structures were repeatedly re-organized. Briefly, in 1909, the Sherman Station became the first-established of these two facilities. In 1928, when the Pendleton Station was established, both stations were administered from the Sherman Station. The administration of those stations was separated in 1938 and remained separated until 1973. During that time interval, the split state:federal appointments of scientists at both stations became fully separated, such that none of the scientists remained as dual employees of the federal and state governments. In 1970, the USDA constructed a new facility at Pendleton. It was named the Columbia Plateau Conservation Research Center (CPCRC), and provided offices for both federal and state scientists and technicians. In 1973, the OAES united the administration of the Sherman Station, Pendleton Station (state component only) and Hermiston Station, under the name Columbia Basin Agricultural Research Center (CBARC), with the administrative leader being located at Pendleton. The Hermiston Station became administratively separated from CBARC in 1985, while the Sherman and Pendleton Stations continued to be jointly administered as CBARC. This discussion of dryland experiment stations and centers contains four sections which focus on the Sherman Station, Pendleton Station, CPCRC and CBARC.

Sherman Station: 1909

Establishment Process (1900-1910)

When James Withycombe, Vice Director of the OAES, conducted field experiments in Sherman County during 1899 he observed what he considered to be non-sustainable wheat production practices, as was introduced in the previous chapter. Withycombe published an Experiment Station bulletin later that year and in so doing, he decried the practice of summer fallow as it was being practiced in that region of low rainfall. A similar expression of alarm over practices in semi-arid central Washington was being expressed at the same time by influential scientists at Washington State College (Scheuerman and McGregor, 2013).

In 1900, Withycombe began advocating the need to establish a branch of the OAES in Sherman County. This concept gained favor but was not immediately enacted. A study of potential sites did not become commissioned, funded, and performed until 1909. The survey of potential sites across eastern Oregon was conducted by H. D. Scudder, an agronomist at Oregon Agricultural College, and W. M. Jardine, the Agronomist-in-Charge of Experiments, USDA, Department of Plant Industries, Division of Dry Land Grains, Washington, D.C. Many potential locations were initially considered but the list was quickly reduced to two finalists; Harney County and Sherman County. The recommendation was thoroughly considered and was heavily influenced by current production practices in each region, and of the likelihood for maximum economic response after additional research was introduced into one of those regions. Ultimately, the final recommendation was determined by the presence of a railroad in Sherman County but not in Harney County. The railroad was considered important not only as a means for transporting additional wheat to market, but also, and as important, for the ability of farming demonstrations to capture maximum visibility by travelers passing through each region. Rail passengers enroute to or from high-traffic destinations such as Portland heavily favored establishing the branch experiment station in Sherman County. Scudder and Jardine's final recommendation was presented to the

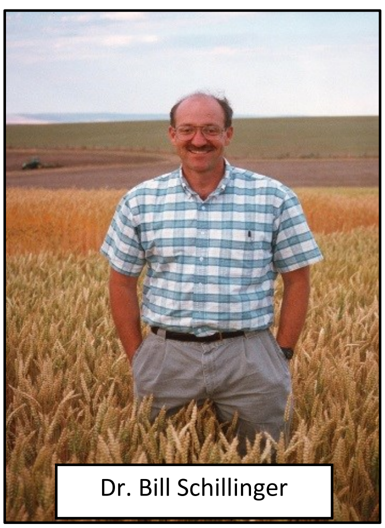
<u>Sherman Station Establishment</u>

1899: Need was determined and stated
1909: Site was selected
1909: Sherman County purchased the land
1909: State Legislature passed enabling act
1910: First buildings were constructed
1910: First experiments were performed

College's Board of Regents in 1909, and is reproduced in its entirety in Appendix 7. The Oregon State Legislature passed a law (SB 85) in 1909 to establish a station "*to investigate and demonstrate the conditions under which useful plants may be grown on dry, arid, or nonirrigated lands of the State of Oregon, and to determine the kinds of plants best adapted for growth on these lands*."

From the very beginning, the Eastern Oregon Dry-Farming Substation enjoyed a harmonious and complementary leadership by the Oregon Agricultural College Experiment Station and the Office of Cereal Investigations in the USDA-BPI. The 1909 and the 1914 Memoranda of Understanding between the OAES and the USDA-BPI each contained some onerous conditions that required detailed attention by the staff at the Sherman Station. The memorandum stated that the OAES would provide land, buildings, teams, machinery, supplies and ordinary labor. The USDA would furnish seed, and an "*assistant who shall be farm superintendent, and be in direct charge of all the field plat experimental work, variety tests, breeding work, etc., at Moro, Oregon*", and other assistants or labor as may be approved by the Secretary of Agriculture, with the assistants being jointly selected by and acceptable to both parties. The investigations were to be planned and conducted jointly by both parties. Seed in excess of that needed for the next sowing must be distributed equally to both parties. "*At the close of each season's experiments a report in detail of the results of the season's work shall be submitted by the agent in direct charge of the field work* … [and] *thrashed samples of the grain of all varieties under experiment and unthrashed samples, when particularly desirable, shall accompany the report ... such report and samples to be delivered not later than December 31, of each year*." The memoranda also contain clauses regarding mandatory acknowledgements of each party in publications and official communications.

The Sherman Station was therefore initially administered primarily as a USDA field station of the USDA-BPI. Other USDA units that also had key roles during the early years included the Biophysical Laboratory, for accumulation of climatological data, and the Office of Forage Investigations (Stephens, 1915). Harry J. C. Umberger, a USDA agronomist from Washington, D.C., was appointed as the first Superintendent (Appendices 1 and 9). He was assisted by Owen Beaty, an Oregon Agricultural College agronomist who served as the station foreman. These two men were responsible for establishing the station. Umberger served on-site most of the year but returned to Washington, D.C. during the winter to write reports and coordinate planning with USDA staff, a practice that became routine for the station's USDA leader for at least the next three decades. The first annual report from the station, in 1910, presented insights into the issues Scudder and Beaty faced during the formative years (Appendix 9).


Dr. Bill Schillinger

Original correspondence between Umberger and others provided the author of this book an opportunity to acquire deep insights into the challenges that occurred during those first two years. The hurdles were vividly displayed in the thousands of original letters, memos, invoices and receipts that are still available for evaluation. Excerpts and synopses from those documents are referenced throughout this book. For instance, it is of interest that one of the first letters, dated July 27, 1909, contained the first mention of David E. Stephens, who was at that time an Executive Assistant for the Grain Investigations Office of the USDA-BPI in Washington, D.C. In 1912, Stephens became the second Superintendent of the Station. He became the longest-serving administrator of Oregon's dryland experiment stations, and his many contributions earned him the reputation of what I'll call the first 'King of Dryland Agronomy in the Pacific Northwest.' As this book is written, the currently-recognized King of Dryland Agronomy is Dr. William R. Schillinger, who has served as Director of Washington State University's Dryland Experiment Station at Lind, WA for the past two decades. The Washington Grains Commission recently called Schillinger 'The Dryland Doctor' (http://wagrains.org/podcast/ episode-77-dr-dryland-bill-schillinger/).

Prior to 1909, branch experiment stations existed near Nephi, Utah, Philbrook (Judith Basin), Montana, and Amarillo, Texas. By late 1911 the USDA-BPI was operating 15 stations across the nation, including the forenamed stations and others in California (Chico), Colorado (Akron), Iowa (Ames), Kansas (Hays), Louisiana (Crowley), Minnesota (St. Paul), North Dakota (Williston), Oregon (Moro), South Dakota (Belle Fourche and Highmore), Texas (Dalhart) and Virginia (Arlington).

From mid-1909 onwards, Harry Umberger relied substantially on guidance from agronomists at existing experiment stations, particularly those in Utah and Montana. Letters containing excerpts such as follows were common. On August 23, 1909, Umberger wrote the following to F. D. Farrell in Nephi, Utah: "*Dear Farrell: The Board of Regents has decided on Moro as the site for the dry farming station … I would like to have you … send me an outline of all your different rotations, as well as any suggestions you may have to offer. I do not expect to get any fall work started here because we have been delayed so long, but do expect to plan the station this fall and be ready to start in a full line of spring work. At present we are waiting for the County Court to purchase the land … I am busy, however, with plans and am taking a topographical survey on the prospective station site.*" Farrell responded as follows on October 15, 1909; "*Dear Umbey: I am enclosing a rough draft of my this fall's planting plans …*" Umberger also wrote the same type of letter to Ernest Adams at Philbrook, Montana. John Stephens, then an agronomist at that station, responded as follows: "*Dear Umberger: Adams requested me to write you regarding our rotation experiments. All of Chilcott's rotations are good ones. It is only a matter of selecting the ones best adapted for your locality. The rotations most promising for this locality are 1 to 9, 14, 16, 15, 17, 42 and different methods of cultivation.*" [Ellery C. Chilcott was Agriculturalist-in-Charge of the Department of Dry Land Agriculture, USDA-BPI, Washington, D.C.]

Umberger also sought guidance for equipment that would be purchased for the Sherman Station. A typical letter was the one sent to Ernest Adams in Montana: "*Dear Ernest: … I would like to know what thresher you are using. Mr. Jardine tells me you have a very desirable one, which serves for both plat threshing and larger work. I would like to know the make, size, etc., and what power is required to drive it. I take it from what he said, that you have a different make from the Baby Vibrator, which we have been using on all of our stations. I would also like to have any suggestions you may have to offer concerning machinery; for instance, anything special in the line of plows or tillage material that you have noticed since you have been there.*"

Buildings

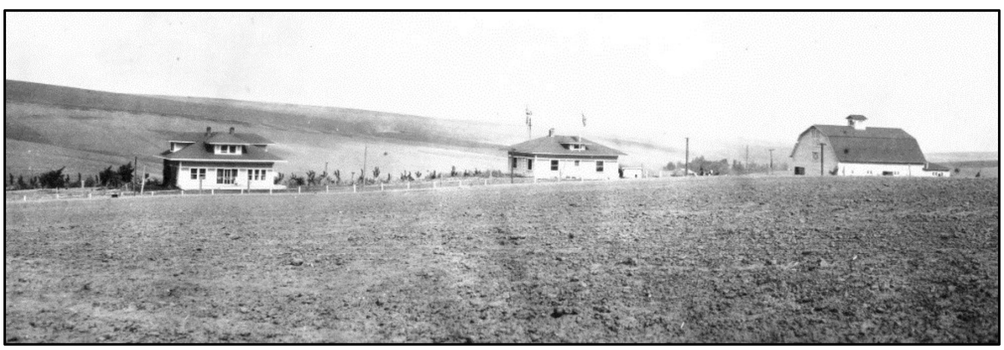
Scudder and Jardine delivered their site-selection recommendation to the Board of Regents during May, 1909. The Board and the Sherman County Court reached agreement on a site as early as August, 1909 (Appendix 7). Construction of buildings and establishment of experiments could not begin until the County purchased the land and fiscal responsibilities of the College and the County were clarified. The Sherman County Court reached agreement with the land owners on September 10, 1909. The County purchased 160 acres from the Eastern Oregon Land Company for $6,400, and 74.5 acres from Mr. Ladru Barnum for $3,280; a total expense of $9,680. The County also designated $7,500 for use in establishing the station.

Further agreements regarding the responsibilities of the County, the College and the USDA needed to be resolved before improvements to the station could begin (Appendix 7). While those legal details were being resolved, Harry Umberger made initial headway by starting to acquire architectural designs for buildings, developing a contour map of the station, and identifying the field equipment and teams required to conduct the experiments. Umberger and Beaty also began to plan divisions of individual experimental fields, locations for fences and roadways, and other details regarding the construction of the station. Plans for the first crops to be planted on the station were finished by October 15, 1909 (Appendix 7). During the following winter a great deal of effort was made to identify crop rotation variables that would be established during 1910. However, the agreement between the College and the County had come to a stalemate during the winter. The State insisted that it would be necessary to deed the land to the State, a move that was strongly opposed by the County. Construction of the buildings was delayed while that issue was being resolved.

Likewise, there was rather intense correspondence during the resolution of differences in opinion regarding the design of the buildings that would be constructed. The Station Superintendent had no intention of accepting the designs presented to the College's architect by Henry Scudder, the College's Professor of Agronomy. As just one example, the following excerpt is taken from a 2-page letter from Umberger to Scudder, dated September 16, 1909. "*Dear Sir: From your last letter I understand that you are sending the architects their original plans rather than those submitted by us. I trust I am in error in this assumption, but would like to say now that the plans forwarded me by the architects are entirely unsatisfactory. The barn plan submitted by the architects is unsatisfactory in every detail. This conclusion is not the result of a hasty glance of possibly an hour's duration, but is a deduction from my own experience and observation, and facts submitted by thoroughly reliable farmers. You are in error when you say that I do not fully* *comprehend the advantages of some of the features. I understand very well that a bin in the middle of the barn is convenient, but it makes that part of the barn one of the hottest places on the farm, because it prevents ventilation over the stalls – the most objectionable feature to be found in any barn. Every farmer with whom I have talked bears out this statement. With this in view, I decided to remedy the evil in the architect's plans, and so planned my sketch. … the plan I submitted I believe entirely satisfactory for our purposes, while that of the architects is entirely unsatisfactory. … it would be just as easy to place my drawings on blue prints as their own. When I sent my plans to you, I requested you to return them. Please see that this is done.*" The plans ultimately accepted and used were those of Umberger rather than those that were promoted by the College administration.

An additional issue causing further delay in construction regarded a dispute as to which agency would be responsible for purchasing the building materials. This and the previously mentioned issues were all very contentious and were not resolved until spring. On February 15, 1910, William J. Kerr, President of the College, included the following statement in a letter to Harry Umberger; "*Otherwise, I see no alternative than to abandon the entire project." Certainly there can be no further delay. The work must proceed at once if at all. It is too late to think of attempting to select a site in any other county*." The President's declaration obviously led to a rapid settlement. Two days later, on February 17, 1910, a deed was signed by the County and the State of Oregon (Appendix 8). The deed gave "*the State a title to the land as long as it was used for experiment purposes*."

Sherman Station (1912) overlooking the railroad line



Sherman Station (September 25, 1915) viewed from the south
(left to right) Superintendent's residence, office with laboratory, and barn

Cargo of sacked wheat enroute to the rail station at Moro;
passing the Sherman Station

Construction of buildings began in late April, 1910, and the three buildings, wind mill, and water well were completed by early October (Appendix 9). The buildings included a Superintendent's house (2 stories with 7 rooms) and a barn (42 × 66 foot) with stalls for 12 horses and two cows, two bins for grain storage, an area for storing hay, and a lean-to style machine shed (18 × 42 foot). The office building consisted of an office (10 × 12 foot), laboratory (14 × 22), and seed room (14 × 26 foot). The OAES also intended to construct a 2-bedroom 'mess house' as a residence for the farm foreman but that plan was cancelled due to insufficient funds. A weather station was also established, with equipment being supplied by the Biophysical Investigations Branch of the USDA-BPI. During that first year, office furniture and miscellaneous tools were purchased, and fencing was installed to protect the experiments from damage caused by animals.

Roads on the station were constructed during the second year and, due to distance from the farmstead to the fields, a machine shed was constructed amidst the experimental fields to protect equipment during the winter, without the necessity to pull it nearly a mile from the fields back to the farmstead.

The Superintendent's house at the Station was entirely destroyed by fire on August 28, 1947. Reconstruction of the house began soon thereafter and it was ready for occupancy in early 1949.

During the 1970s the USDA-Soil Conservation Service (SCS) participated in the reconstruction of grass roadways and contour channels between fields to reduce the amount of soil eroding from the roads and fields.

The original barn was sold and moved to a residence west of Moro during 1974. New machine sheds and a shop were constructed and remain on the Station at this time.

The original office building was demolished during 2011 and was replaced by a new office structure, which was dedicated on June 13, 2012. The new structure was a joint venture between Sherman County and Oregon State University. The building includes a meeting room and five offices that initially accommodated the Sherman Station Farm Manager, all staff of the Sherman County Extension Service, the Sherman County Weed Master, and the Sherman County Planner. A new chemical storage and handling facility was constructed during 2017.

Superintendent's residence - 1938

Office building - 2016

Grounds

The land now occupied by the station had been cropped to wheat alternated with cultivated fallow for about 20 years before the station was established in 1909. The first Superintendent, Harry Umberger, intended to plow all cultivatable land during the fall of 1909 and spring of 1910 to get it ready for planting during the spring of 1910. But the plowing was delayed by disagreements between the College and the County. The formative agreement stated that experimental work could not begin before the buildings and permanent improvements were completed and turned over to the College. Primary emphasis during 1909 was therefore placed on preparing land for experimentation. The final deed was signed on February 17, 1910 and main structures of the physical facility were constructed that year. All of the land was plowed during early 1910, and most of the acreage was summer fallowed during 1910 to reduce the weediness of the fields.

In March, before construction began on buildings and fences, Umberger started to purchase field equipment and teams of draft horses. Two teams were purchased in March and most of the equipment had been purchased by July 1. Umberger bought the following equipment from the John Deere Plow Company; 14-inch 2-bottom plow, 2-way 14-inch plow, and 2-row corn planter. His purchases from the Planet Junior Company included a wheel plow, 5-tooth garden plow and garden drill. Purchases from the Parlin and Orendorff Company included a 12-inch 2-bottom gang plow, a 26-inch disk plow, corrugated roller, two packers, a 4-section harrow and harrow cart, an alfalfa harrow and truck, a lister, a Superior grain drill (14-hole × 7-inch row spacing), a cultivator, and a steel farm truck with doubletrees and neck yoke (this was a non-motorized flat-bed wagon). Umberger also purchased an Ellis Keystone grain separator with a folding straw carrier, bagger, and a belt to connect to an engine. A 6-horsepower portable gasoline engine was purchased from the International Harvester Company to provide power for the separator.

Forty acres were planted to Bluestem wheat that was harvested as a source of seed for use in experiments during 1911. Some small variety tests were also planted and harvested during 1910 "*for the purpose of showing in what direction to avoid useless work in the future*." The demonstration plantings included varieties of spring wheat, barley, oats, corn, millet, field peas, sorghums, potatoes, and grasses

(Scudder and Beaty, 1910; Appendix 9). Lastly, a summer fallow tillage trial was established. In the fall of 1910 they planted a large assortment of winter cereals that included wheat, oats, barley, and emmer (Appendix 9). Harry Umberger stated in the 1911 Annual Report from the 'Eastern Oregon Dry Farming Substation' that the work in 1911 "*should really be considered the first year's work*." Winter wheat was to take on particular importance at the national level during January 1911, as evidenced by a seminar on that topic in Washington, D.C., at which time it was emphasized that winter wheat had become a major crop in seven of the Great Plains states and therefore warranted evaluation in a uniform experiment to be performed on all 15 of the USDA's experiment stations, including Moro, beginning immediately (Appendix 9).

At one time there were 26 work horses maintained at the Sherman Station. The most horses required for any one job occurred during plowing and harvest seasons. The use of horses was still common in 1938, as surmised from a statement in the *Report of Sherman County Economic Conference*; Moro, Oregon; February 19, 1938. The entry stated that the number of horses in the County decreased "… *from nearly 9,000 head in 1920 to approximately 3,800 in 1937 and still decreasing*." Likewise, there were two related entries in the Station's Annual Report: "*All of the pasture land was seeded with a two-horse drill …*" and "*They received two cultivations with a one-horse cultivator during the growing season*."

Only minor adjustment has been made to the Station boundary during the past 110 years. During 2013, the OAES agreed with the Sherman County Court to cede unused OAES acres along the north boundary, along Barnum Creek, to enable the City of Moro to expand and improve its' waste-water management infrastructure. In return, the Station was provided responsibility for farming 15 acres south of the then-existing Station boundary, west of the Sherman County Fairground. The Station pays the County an annual fee for that lease. The additional farmed acreage was reduced to 14 acres during 2019, when the County constructed a Weed Master's facility near the fairground.

Administrators and Staff

As stated earlier, Harry Umberger was the first Superintendent. However, in early 1911, soon after the station had been established, both Umberger and his farm foreman, Owen Beaty, began considering employment opportunities at other locations. In late 1911, upon death of his father in Kansas and the impending birth of their first child, Umberger and his wife moved to Manhattan, Kansas. He was immediately hired by Kansas State Agricultural College. He first served as an Extension Soil Scientist. In recognition of his long and fruitful career as Dean of Extension, the Agricultural Extension Building at Kansas State University carries his name. At about the same time that Umberger left Moro, Beaty moved to Fossil, Oregon to become the Wheeler County Extension Agent.

Sherman Station Superintendents: 1909-1973	
Mr. Harry J.C. Umberger	1909-1911
Mr. David E. Stephens	1912-1938
Mr. Merrill M. Oveson	1938-1948
Mr. George A. Mitchell	1949-1953
Mr. William E. Hall	1953-1964
Mr. Jack T. McDermid	1964-1973
Assistant Superintendents:	
Mr. C. Edwin Hill	1912-1918
Mr. George A. Mitchell	1921-1928
Mr. Merrill M. Oveson	1928-1938

David Stephens moved from his USDA position in Washington, D.C. during early 1912 to become the Superintendent at the Sherman Station (Appendix 1). That same year, Stephens appointed Mr. C. Edwin Hill, an alumnus of the Oregon Agricultural College, as an Assistant to the Superintendent. Hill continued as Assistant Superintendent until 1918 and, in 1921, was succeeded in that role by Mr. George A. Mitchell.

Stephens continued as Superintendent of the Sherman Station for 25 years, becoming the longest-serving, most-influential, most-visionary, and most-legendary administrator in the history of the Station. When the Pendleton Station was established in 1928, Stephens was appointed as the Superintendent of both stations. He served that dual administrative role for a decade until he returned to Washington, D.C. in 1938 to once again work at USDA headquarters. In 1928, when Stephens began administering both dryland research stations in Oregon, George Mitchell was moved to Pendleton to become Assistant Superintendent of the Pendleton Station and to coordinate the establishment and first experiments at that station. At the same time, Mr. Merrill Oveson was hired as Assistant Superintendent of the Sherman Station.

Upon Stephen's departure in 1938, Oveson became Superintendent of the Sherman Station and Mitchell became Superintendent of the Pendleton Station. Oveson served for nine years before the administrative positions at the Sherman Station and the Pendleton Station were switched late in 1948. The switch was prompted by a USDA initiative to invest more heavily into research and personnel at the

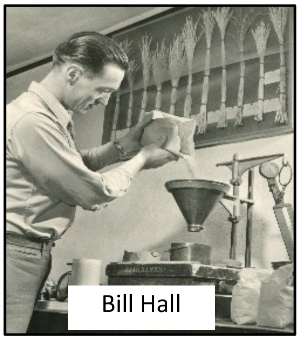
Pendleton Station. However, that initiative carried with it a provision that the USDA would do so only if Oregon State College transferred Oveson to Pendleton to serve as the Superintendent. Oveson was therefore moved to Pendleton and Mitchell was moved back to Moro. Mitchell resigned four years after returning to Moro. William 'Bill' Hall became the next Superintendent of the Sherman Station. He had been a research assistant at Moro since 1947. Hall held the Superintendent position for seven years before enrolling in a Ph.D. program at Michigan State University. He was a graduate student for two years before he was ordered by the College to either return to Moro or resign. Hall chose to finish his schooling.

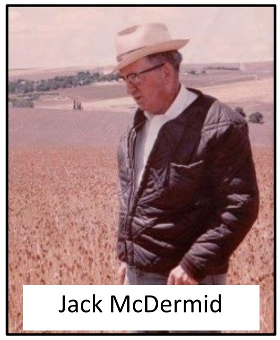
Jack McDermid, who worked at the Station as an experimental farmer, succeeded Hall as the Superintendent. McDermid had previous experience as the Superintendent of the Red Soils Experiment Station at Oregon City until that station was closed in 1964. All previous administrators had been USDA employees with split administrative oversight by USDA and the Oregon Agricultural College. McDermid and all subsequent administrators have been employees of Oregon State University. McDermid served as the Superintendent until he suffered a fatal heart attack on January 14, 1973.


Harry Umberger - 1905


David Stephens - 1925


Merrill Oveson - 1953


Bill Hall


Jack McDermid


Dr. Charles Rohde

In 1973, Dr. Charles Rohde was Superintendent of the Pendleton Station. He conducted some of his research at the Sherman Station. On July 1, 1973, shortly after McDermid's passing, the Sherman Station and Pendleton Station were once again linked as a single administrative unit, as had occurred when Stephens was Superintendent. However, on this occasion, Rohde became responsible for administration at three newly-linked branch experiment stations; Pendleton, Sherman and Hermiston. Simultaneously, the combination of the three stations was named the Columbia Basin Agricultural Research Center (CBARC). Local coordinators of activities at the Sherman Station have been known as farm managers since that time.

The first non-administrative staff member at the Sherman Station was Owen Beaty. He served as the farm foreman from 1910 to 1912. R. B. Hoskinson became farm foreman in 1914 and continued in that role until he retired in 1955. Harold Hailey was the farm foreman from 1955 until 1960. Linden Mersinger served as an experimental farmer from 1945 and became farm foreman from 1960 until 1975. G. Delbert Smith was the farm manager of the Sherman Station between 1975 until 1984. In 1984, Scott Case transferred to the Sherman Station after serving in a similar position at the Pendleton Station. Case served as farm manager at Moro until 1992, at which time reductions in funding for statewide public services led to Case's position being eliminated. Erling Jacobsen, who had worked as a farmer at the station since 1985, then managed the Sherman Station until he retired in 2015. Kyle Bender became the farm manager in 2016.

Operation of the Sherman Station required the assistance of many more people than are or could be acknowledged here. Names of some of those individuals are shown in a summary of the Station's first 50 years (Hall, 1961) and in the listing of professional personnel at the stations and centers for individual Annual Reports (Appendix 5). Many more short-term employees also served important roles during peak seasons. A complete listing of workers at the station is not available. However, some key employees specifically named in Annual Reports from 1910 to 1972 included: C. Edwin Hill (assistant to Stephens; first mentioned in 1915), W.S. Carpenter (replaced Hill; 1919), J. A. Clark (cereal breeding and testing; 1919), H. M. Woolman (cereal breeding and testing; 1921), Rachel Bayne (secretary; 1923), Burton B. Bayles (cereal breeding and testing; 1925), J. Foster Martin (cereal breeding and testing; 1927; he later moved to Pendleton), Robert B. Webb (cereal breeding and testing; 1930), Robert W. Henderson (cereal breeding and testing; 1938), Joseph Belanger (stubble-mulch summer fallow systems; 1938; he later moved to the Pendleton Station), Leon V. Hubbard (cereal breeding and testing; 1941), O. S. Weaver (cereal breeding and testing; 1943), Dean Swan (weed control; 1956), W. F. Wright (tillage investigations; 1957), and Donald Graham (Soil Scientist; 1961).

Pendleton Station: 1928

Establishment Process (1925-1930)

Establishment of the dryland branch experiment station at Moro drew much publicity in eastern Oregon. Many articles appeared in newspapers in The Dalles, Moro, Heppner, Burns and Pendleton, among others. One article with the title of "The Dry Land Station" was published in the East Oregonian on August 9, 1909. The article stated the editor's expectations for staffing the station, for development of a method to produce crops each year in the low-rainfall region that was already in a 2-year rotation of winter wheat with summer fallow. What was equally important was another article in that same newspaper, presumably written by E. B. Aldrich, Editor of the East Oregonian. The untitled article stated "*Even though a dry land experiment farm is to be established at Moro it would not be amiss to have a station in this county. The East Oregonian believes that a station conducted by this county and working either in conjunction with the government men or along independent lines, would be of vast benefit to the county*." That statement may have been the first public mention of the need for a dryland branch experiment station in Umatilla County. While it is presumed that there was additional discussion, no formal action appears to have been documented for at least a decade.

Issues regarding dryland agricultural practices throughout eastern Oregon were handled by the Sherman Station from 1911 until 1930, and even beyond, as will be explained later. An example pertinent to this discussion is in the following question, which was stated in a 2-page letter from Dave Stephens to M.A. McCall, Superintendent of the Adams Branch Experiment Station near Lind, Washington. In the letter dated November 3, 1921, Stephens asked "*What is the Experiment Station's recommendation to farmers in regard to burning the straw in the Palouse country? Umatilla County farmers tell me that they are obliged to burn their straw every year. There is some difference of opinion among farmers as to whether this is really injurious but practically all of them follow the practice of burning*."

Starting in 1919, Fred Bennion, the new Umatilla County Extension Service Agricultural Agent, became an important collaborator in experiments being conducted in Umatilla County by scientists from the Sherman Station. He immediately began collaborating with Dave Stephens by hosting demonstrations of small grain varieties and techniques to treat seed for controlling common bunt. Within a few years, those demonstrations were elevated into regional trials to evaluate all grain varieties under conditions in Umatilla County. The following excerpt was from a 3-page typewritten report prepared in 1923 as an article for publication in the Pendleton Round-Up special edition of the East Oregonian newspaper. The title was "*New Experiments with Grain in Umatilla County*." Passages included the following: "*In the fall of 1922, cooperative wheat and barley experiments were started in Umatilla County by County Agent Fred Bennion and the Moro Experiment Station for the purpose mainly of determining whether any of the smut-resistant and smut-immune wheat varieties developed at the Moro and Pullman Experiment Stations would be sufficiently productive to warrant their being grown by farmers of Umatilla County. This wheat and barley nursery on Elmer McCormack's ranch was one of the special points of interest of the field tour held on July 20, when a large crowd of farmers inspected the many wheat and barley varieties being tested there. ... The most promising varieties will be continued in similar trials for at least two years more after which the best ones can be determined with some degree of certainty*." "*The wheats and barleys in the nursery near Pendleton were cut and shipped to Moro for thrashing in a machine especially built for thrashing nursery rows.*" [the yield data for smut-immune and smut-resistant varieties was compared to the yield of Hybrid 128, the most

<u>Pendleton Station Establishment</u>

1909: Need was first stated in a newspaper
1925: Need became well defined and re-stated
1928: Site was selected
1928: Umatilla County purchased the land
1928: State Legislature passed an enabling act
1928: Land lease signed by Experiment Station and USDA Bureau of Plant Industry
1929: Construction of first buildings
1930: First experiments were established
1931: First field day

widely-grown wheat in Umatilla County at that time]. "*The fact that so many of these smut-resistant wheat varieties produced higher yields than Hybrid 128 is significant and will no doubt mean that Umatilla County farmers will ultimately substitute for that smut-susceptible variety a higher yielding one that will not even have to be treated before sowing*." "*Smutty seed, without treatment, was sown of all the above-named varieties but the resulting crop of no variety contained smut except Hybrid 128*." "[In comparison,] *At the Moro Station* [where there was very little smut in the crop] *the only smut-resistant variety that exceeded the yield of Hybrid 128 was Turkey 1571C*." *"... yields of these varieties near Pendleton when compared with the yields ... at the Moro and Union Stations and at similar nurseries in Morrow and Malheur Counties, will be of great aid in picking out the best varieties for general culture in eastern Oregon*."

By 1926, Bennion was conducting or coordinating a large number of demonstrations and experiments in Umatilla County. Many of those tests were in collaboration with Dave Stephens. Bennion evaluated fertilizer sources and application rates, nurseries to evaluate winter wheat, spring wheat, barley, oats, rye, corn, legumes such as sweet clover and alfalfa, and various types of hay. He also evaluated various methods to control morning glory, gophers, rabbits, rats and squirrels. Bennion also inspected and certified grain crops being produced for sale of seed.

In 1925, Bennion began to lobby for the establishment of a dryland experiment station in the higher-precipitation area of Umatilla County, where the wheat industry was already well developed but needed additional guidance that could only be provided by government research. The Confederated Tribes of the Umatilla Indian Reservation also hosted experiments by scientists from the Sherman Station. Major Omar Babcock, Superintendent of the Umatilla Indian Agency, had also requested that Oregon State College establish a local branch experiment station on CTUIR land in Umatilla County. Dave Stephens, Superintendent of the Sherman Station, was the key individual who initially communicated with these and other influential citizens in Umatilla County. Insights into some of the more formal discussions are presented below.

On April 21, 1925, Fred Bennion wrote a letter to James Jardine, Director of the Experiment Station, at Corvallis. He stated "*Major Babcock, Superintendent of the Indian Agency here, was in the office Saturday discussing the possibility of carrying on some experimental work on the Indian lands. You know that many of the best wheat lands in the county are owned by Indians and leased by the Whites. It is in this district that a system of farming could be worked out whereby much of the summer fallow acreage could be eliminated. It was in this territory that we expected to establish a crop rotation demonstration farm according to the legislative act that was vetoed by the Governor. Major Babcock was very much interested in seeing this work carried on, and was so thoroughly impressed with its value that he offered to secure whatever land was necessary and make a ten-year lease, without any charges, to the Oregon Experiment Station. This land would be part of the Indian Agency farm just south of Mission, and is typical of the territory we would desire to work in. The Agency barns, tool sheds, etc. could be used. Later he discussed the matter with Mr. Aldrich* [E.B. Aldrich, Editor of the East Oregonian newspaper], *who called me down to his office where we went over the possibilities. Mr. Aldrich stated that he would write you, but requested me to do the same. If there is any possibility of starting this work this fall we should like very much to see it done. ...*" Bennion also sent a copy of the letter to Dave Stephens, along with some handwritten notes *"... a copy of a letter to Director Jardine which gives a new angle on the crop rotation work in this county. I hope that sufficient funds can be raised some way to start on this work this fall*."

Two days later, George Hyslop wrote a letter to Dave Stephens to request his opinion regarding this issue. Stephens responded with a 3-page letter to Hyslop on April 27, including the following statements. "*Replying to your letter of the 23rd inst. with reference to the proposed establishment of an experimental farm in Umatilla County, will state that your letter to Mr. Aldrich is all right. ... we should not appear too eager to jump into something which may mean trouble for us later on, and especially we should impress upon the minds of the Umatilla County people that such experimental work as they propose to have us do is expensive. In addition to the items of expense you mention, you might add that certain equipment would likely have to be purchased*."…"*I doubt the advisability of starting an experiment farm in Umatilla County without first having a state appropriation made for its maintenance*."…"*You might elaborate your suggestion to Aldrich about the great desirability and feasibility of County Agent Bennion arranging for a series of rather permanent crop rotation demonstrations with several of his influential, intelligent and prosperous farmers. With his great organizing ability some ... worthwhile innovations might be started along this line,…*" "*… Bennion has an opportunity, I think, of accomplishing some startling results in* *certain sections of his county by starting some crop rotation demonstrations that might, if conducted properly, result in as much or more good so far as getting new cropping practices started as would the establishment of an experiment station*."

The issue gained significant traction over the next two years. On March 18, 1927, Stephens wrote a 1-page letter to Mr. Walter A. Holt, who by that time was the new Extension Agent in Umatilla County. The note in its entirety was as follows: "*After leaving you yesterday I saw Mr. Aldrich and at his suggestion we called up a number of farmers and talked to them about the location of the experimental farm in Umatilla Co. I talked to Messrs. Thompson, Hales, Hill, Ritner, and Curl. Some of them men thought that the Indian Agency land might not be just what we wanted, and I rather encouraged them in this belief on the ground that we were now conducting rotation experiments at Moro on wheat land that averages about 30 bushels per acre in yield after good summer fallow, and that the land chosen for this work in Umatilla should be about 40 bushel wheat land. I thought it would do no harm and perhaps some good to do a little more investigating in regard to suitable sites. Some of them thought that the County Court could be prevailed upon to lease, or perhaps buy outright, the kind of land we needed in case the Indian Agency land was not suitable. Ritner stated that he would call a meeting of the Agricultural Committee of the Chamber of Commerce and of the Farm Bureau to further discuss this matter and ascertain if other sites would be available. They will of course expect you to assist them in their deliberations and investigation. I promised that I would return to Pendleton on March 26, so that we might, if possible, definitely determine upon a suitable site. Some time before that date, or when we plant the nursery, we shall make some borings on the Indian Agency land, as this will aid us in determining whether this land will be suited to our needs.*"

Stephens wrote another letter to Holt on September 21, 1927. "*I should be very much pleased if Mr. Thompson could negotiate to buy or rent the tract of land near Adams which you mention. It looked very uniform and would be worth considerably more, I think, than the Rogers tract, especially for our purpose. … I would suggest to the County Court that each one of them look over this land and decide for themselves if they think the land is worth the price.*" "*If convenient for you, I wish you would arrange to help Mitchell plant the nursery either on the 27th or the afternoon of the 28th of this month. Mitchell has to be in Enterprise on the 26th and it would save us time and money if he could plant the nursery either on his way up or on his way back. … If the location of the experimental farm remains uncertain, I think we should try to get the same tract of land from Mr. McCormach. We have had two good nurseries there, and I hope you can get him to let us have the land again. Of course if the farm is definitely located, it would be quite an advantage to have the nursery as near to the farm as possible*." Subsequent correspondence between Holt and Stephens left no doubt that Holt, the Umatilla County Agent, coordinated weed control and summer fallow tillage practices and timing with the landowner on behalf of Dave Stephens during the remainder of the 1927-1928 crop year. Holt also kept Stephens updated on negotiations between the County Court and landowners who were being asked to sell land for the new experiment station.

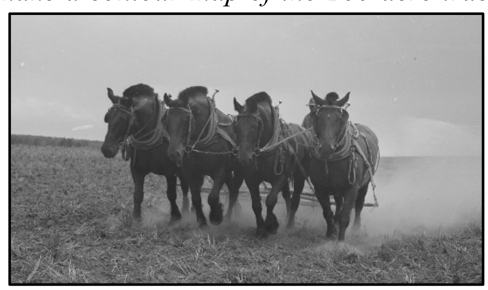
On June 15, 1928, Stephens sent a 2-page letter James Jardine, at Corvallis. "*I spent Thursday and part of Wednesday of this week at Pendleton in conference with the County Court and County Agent in regard to securing land for the experimental farm. We did not make much progress. The lady who owns the land adjacent to that already purchased by the County refuses to sell. The court has very carefully considered the advisability of instituting condemnation proceedings to acquire the forty acres of land adjoining the present tract, but was hesitant to do this because …*" "*Two other sites are available, one of 160 acres owned by a lady who is willing to sell, and another of about 100 acres owned by Mr. L. L. Rogers. The 160-acre tract appears to be the best and most uniform land. Both tracts, however, are off the main traveled roads and so far away from a town that an extra building would have to be erected for a mess-house. … this consideration should not overshadow the suitability and uniformity of the soil for our purpose*." "*The County Court also is up against the proposition of financing the purchase of the additional land, without having the item in the county budget and approved by the people. … it might not be easy to arrange for the purchase of the 160 acre tract, as the purchase price would be in the neighborhood of $25,000*." "*If you and Prof. Hyslop will have time to do so when you are in Pendleton next week with the Board of Regents, I wish you would look at the two sites that are available. Mr. Rogers was willing to sell his land across the road just east of the present site, but the land has considerable morning glory on it and therefore I think its purchase would not be advisable*."

On September 11, 1928, Jardine sent a 1-page letter to a Mr. Smith, the Business Manager of the Oregon Agricultural College. "*I am enclosing three copies of a lease between Umatilla County and the State Agricultural College covering 160 acres of land which the County is furnishing for a crop rotation* *experiment station. This action is to carry out an understanding whereby the County furnishes the land. The State of Oregon has made a continuing appropriation of $3,000 for crop rotation experiments in Umatilla County and crop nursery work east of the Cascades. The Federal Government appropriated $10,000 to the Office of Dry Land Agriculture, Bureau of Plant Industry, to assist in establishing and maintaining a crop rotation experiment station in Umatilla County*." "*After going through the attached lease with you some days ago … It was immediately forwarded to Superintendent Stephens at Pendleton. He went over the land again, and, acting for the Station, secured the signatures of three members of the County Court at Pendleton. The lease is now ready for signature of the Regents. We would like to proceed at once with plans for seeding the area this fall and for buildings*. …"

On that same day, September 11, 1928, Jardine also sent a letter to Stephens. "… *As you know, I have personally decided that the best way to handle those stations is to have them both under your supervision, with a good young man at each station.*" "*We will have to decide rather carefully on the most effective way to use the Federal and State funds. We might consider using Federal funds to purchase seed and plant the crop this fall, and save our funds for buildings to the maximum. The more nearly the State can own the land and buildings the less difficulty we will have in arranging our contract. Also, the Federal funds, no doubt, can be used for all manner of equipment and supplies without necessitating a 100-year contract*."

It is clear that the Director of the OAES expanded Dave Stephens' responsibilities such that he would become the Superintendent of the Pendleton Station as well as the Sherman Station. Stephens transferred George Mitchell, his assistant at Moro, to provide local oversight for establishing the new station near Pendleton. It is not surprising, therefore, that most of the early experiments at Pendleton were patterned directly after those already in existence at Moro, affording the opportunity to examine crop varieties and tillage, rotation, fertilizer treatments in two contrasting climatic zones. A copy of the lease for the Pendleton Station is reproduced in Appendix 10.

It is also clear that Stephens began to personally direct activities at the Pendleton Station. This was evident in a letter to Holt, dated September 19, 1928. "*I wonder if you could find time to consult with your County Engineer and ascertain from him whether he could make a contour map of the 160-acre tract of land to be used for the experiment station. … Twenty-five foot contours would be satisfactory. We need this information at once, as the Director thinks that the buildings cannot be located in their proper place without first having a contour map*." "*I wish you would drop a note to two or more farmers and ask them to quote me a price, in writing, on 180 bushels of certified seed of Hybrid 128, delivered to the experiment station. It is necessary to get bids in writing in order to pay for the seed from Government funds*."…"*See if any farmers in the vicinity of the station would be interested in harrowing the ground for us next week. Arrange with them to go ahead and give the entire tract a good harrowing if you think their charge is reasonable*."…"*We hope to have a man on the job not later than October 1, after which we trust it will not be necessary to trouble you so often*." In another letter to a colleague in Madison, Wisconsin, dated October 18, Stephens described the new station and stated "… *and Mitchell is there now looking after seeding*."



Rod weeding at Pendleton – 1933
(a tractor was purchased in 1928 but the transition of power source was gradual)

Horse-drawn Van Brunt seed drill purchased for Pendleton Station in 1928
(now at Sherman County Historical Museum)

Stephens also took responsibility for purchasing equipment and a team for the new station. On October 27, 1928, he wrote to R. F. Whelan, Office of Dry Land Agriculture, USDA, Washington, D.C. "*I am inclosing a voucher for $174.75 for one drill and harrow purchased from the John Deere Plow Company, Portland, Oregon. … As you probably know the title for the land for the Co-operative Field Station at Pendleton was not acquired until late in September, and it was necessary to prepare the land and seed it at the earliest possible date. … The Van Brunt drill was a little cheaper than the Superior, and was better suited to our needs, as we can obtain for this drill a set of deep furrow openers* *to experiment with furrow seeding. ... The deep furrow attachments for the Van Brunt drill cost in the neighborhood of $50.00. The company* [John Deere] *is loaning us a set of these attachments for use this fall, and if they prove satisfactory we shall want to purchase a set, because there is quite an interest in Umatilla County in the deep furrow seeding*." …"*We will have to purchase for the Pendleton Station four good horses. These may cost us as much as $200.00 each*."…"*Mitchell will have a number of vouchers to send in at the end of the month,… He has purchased about 180 bushels of seed at approximately $1.35 a bushel…*"

Stephens hands-on style of directly administering the Pendleton Station continued for many years. On March 11, 1930, he sent a letter to the Dean of the Forestry Department at Oregon Agricultural College. "*I wish you would ship to George A. Mitchell, Pendleton Field Station, Pendleton, Oregon, the following trees: …*" Stephens listed 700 trees (see Chapter 11). His letter continued *"I understand that you do not have any Caragana or Russian olive trees. We shall get some of these from Mandan, North Dakota, if possible. I wish you would also send to me, addressed to Moro, about 100 Chinese elm, if you can spare that many.*" The next day he sent a letter to his brother, John M. Stephens, at the USDA Office of Dry Land Agriculture, Washington, D.C. "*We are planning to plant a lot of trees on the Pendleton Station this spring, and there are a few varieties which we are unable to get from the Forestry Department here. I wonder if we could get about 50 each of the following varieties from one of your Great Plains field stations; Caragana, Russian olive and Black Hill spruce. I am having sent to Pendleton 700 Western yellow pine, Scotch pine, Austrian pine, black locust, Chinese elm and box elder. If you have any new introductions that you think would be adapted to the Pendleton country we should be glad to have you include some of them in the shipment with the other trees. I would write directly to Mandan but I do not know who is in charge there during your absence*." He then continued with these additional thoughts. "*The building program is progressing much more slowly than we should like. We are greatly handicapped because we do not have enough funds to put up all the necessary buildings this year. Our house cost us about $1500 more than it should have. However, I think we have a very well built house. I hope we can put up an office building this summer*."…"*Mitchell seems to be very much interested in the work he is doing there, and I am wondering what sort of an impression he is making on you folks in Washington from the reports he is sending in of his work*."

In 1927, the OAES consisted of the home facility at Corvallis and branch experiment stations near Union (established in 1901), Moro (1909), Hermiston (1909), and Hood River (1913). The official name of the newly established research center at Pendleton was the Pendleton Field Station. That name continued from 1928 until it was changed to the Pendleton Branch Experiment Station in 1942, and to the Pendleton Experiment Station in 1962. In 1973, three stations were merged into a single administrative unit, which became named the Columbia Basin Agricultural Research Center, including the Pendleton Experiment Station, Sherman Experiment Station, and Hermiston Research Center.

Buildings

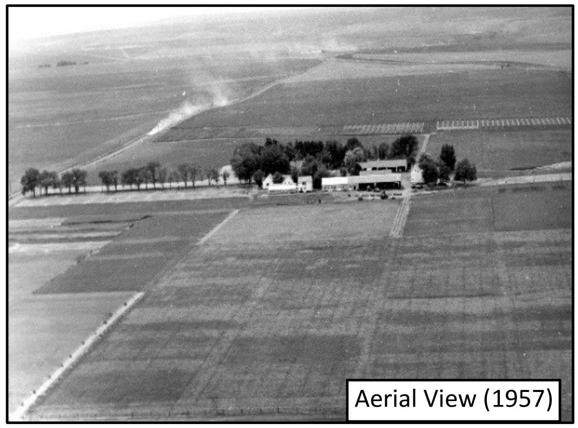
The 2-story Superintendent's residence, an implement shed (20 x 100 feet), and a water well were constructed late in 1929. A 2-story 'foreman's cottage' and a building to provide offices and a laboratory were constructed in 1931. The facility was expanded during 1932 by constructing a building for storing seed (32 x 19 feet) and to serve as a barn (32 x 45 feet) for three horses, one cow, and storage of 20 tons of hay.

Original buildings were renovated periodically and additional buildings were constructed periodically to meet expanding and evolving needs. A building consisting of a machine shed (30 x 50 feet) and a machine storage shed (30 x 100 feet) was constructed in 1951. The machine shed provided a facility to repair and remodel farm equipment. By 1953, additions to the staff had exceeded the capacity of existing facilities to accommodate all individuals and research projects. This deficiency was alleviated in 1954, when the Oregon Wheat Commission provided $23,000 to enlarge the facility. Additions were made to expand the size of the office building and to convert the basement of the office building into a soils laboratory.

Pendleton Station buildings (1930)

At the same time, the Commission also provided funds to extend the machine storage building by an additional 30 x 50 feet. That expansion provided indoor work space and a fire-proof seed-storage room for use in the wheat breeding program.

A greenhouse (24 x 52 feet) and a head house (potting shed; 25 x 28 feet) with an apartment on the second floor was constructed in 1957. The heating unit in the head house provided heat for both the greenhouse and the office building, and opened the entire basement of the office building for enlargement of the soil testing laboratory. The headhouse also included a walk-in cooler consisting of two well-insulated rooms; one of which was initially used to freeze wheat plants for studies of winter-hardiness, and the second of which was used to pre-harden plants before they were moved to the freezing chamber.


Aerial View (1957)

A root-washing building (20 x 20 feet) was constructed in 1988 to improve the efficiency of washing soil from roots of plants dug from field experiments or grown in pots in the greenhouse. A USDA grant for $162,960 in 1991 provided funding to construct a second greenhouse (42 x 60 feet) and headhouse (23 x 50 feet). An additional $50,000 from other sources was used to construct benches for the greenhouse and cabinets, counters, sinks, and other features within the headhouse. A farm foreman's office building (17 x 32 feet) was established in 1994. That facility included space to consolidate all farm records and supplies, as well as information relating to pesticide safety and regulations. Enclosed multi-purpose, partially-enclosed pole barns were constructed during 1998 (45 x 120 feet) and 2002 (40 x 120 feet). The pole barns provided additional space to store equipment and supplies, and also provided sample processing areas that could provide shelter during inclement weather. A small building was constructed in 2013 to provide isolated, indoor space for housing equipment that could apply herbicide sprays to plants or soils in greenhouse pots.

In 2015, the Superintendent's residence was demolished and that land area is currently used to park vehicles and equipment. Likewise, in 2016, the walk-in coolers that had been used for studies of winterhardiness (1950s), stripe rust (1950s-1990s), and root and crown diseases (1990s-2015) was demolished and replaced with modern growth chambers.


Superintendent's residence
(before demolition in 2016)

Grounds

The land occupied by the station had been cropped to wheat alternated with cultivated fallow since about 1890 (Stephens, 1915). The facility was surveyed and the first experiments were established during 1929. The following information from a news release with the title "*The Pendleton Field Station*" is repeated in its entirety. "*An enlargement of the dry-farm crop rotation work contemplated in the act passed by the 1927 Legislature (H.B. #590) was made possible by securing Federal Cooperation through the Office of Dry Land Agriculture of the Bureau of Plant Industry. In accordance with a memorandum of understanding with this Bureau and the Oregon Agricultural Experiment Station, effected since Dec. 1, 1928, approximately $9000 annually will be allotted by the federal government for crop-rotation, tillage, and fertilizer studies on the dry lands of the Columbia Basin of Oregon. A tract of 160 acres of suitable land to conduct these experiments was provided by the County of Umatilla and a new Branch Station, the Pendleton Field Station, was established through the lease of this land by Umatilla County to the State of Oregon. The Station is located on productive Umatilla County wheat land about eleven miles northeast of the City of Pendleton.*"

"*The station farm was all in fallow in 1928 and was uniformly cropped to winter wheat in 1929, with the exception of a few acres used for grain varietal trials* [10 entries of winter wheat and 8 entries of spring wheat and oats were each replicated 3 times]. *The portion of the field used for crop rotation and tillage* *experiments was harvested in one-tenth acre units to secure information on soil variability in advance of starting the experimental work*."

"*A comprehensive series of crop-rotation, tillage and fertilizer experiments were started in the fall of 1929, mainly for the purpose of (1) ascertaining the most practical and economical methods of maintaining and increasing soil fertility of wheat lands that have been continuously cropped to grain for about half a century, (2) studying the effect on crop yield and soil fertility of various cropping systems, with and without fallow, and (3) determining the effect on yield and quality of wheat of varying tillage methods in connection with the growing of wheat after fallow. In addition to these experiments, varietal testing work with cereals, legumes, and other crops will be conducted*."

"*Largely from receipts from the sale of the 1929 crop, a superintendent's residence and an implement shed have been constructed. A drilled well, 285 feet deep, which provides ample water for household use, has been dug. An office and laboratory building, a storage room for seed, and a small barn are urgently needed and will be erected as soon as funds are available*."

The 160-acre tract of land owned by Umatilla County was reduced by 10 acres when the USDA invested in additional facilities at the research station during 1970. Umatilla County sold a 10-acre parcel to the U.S. government to meet a requirement that USDA buildings could only be constructed on land owned by the federal government.

In 1950, the station established long-term leases on three nearby farms. Those leases encompassed 323 additional acres that were operated by station staff and equipment. Those leases were required for research on agronomic studies in precipitation zones that differed from those at the Pendleton Station (15.7 inches). The three leased sites, called pilot farms, included the Hill Pilot Farm (11.7 inches, near Helix), King Pilot Farm (12.5 inches, near Helix), and the Crow Pilot Farm (16.4 inches, near Weston). The Pendleton Station therefore controlled and conducted experiments on 483 acres of land (160 'owned' and 323 leased acres) for about two decades (1950-1970). Additionally, each of the scientists routinely conducted shorter-term experiments throughout eastern Oregon on land that was donated by collaborating farmers.

Leasing of land for longer-term experiments re-emerged during 2004, when 37 acres adjacent to the northern border of the Pendleton Station was leased. An adjoining 17 acres was also leased in 2014. The owner of the 37-acre leased block stated an intent to sell that property in 2015, threatening the longevity of the rotation that had been established for experimental purposes. In response, the Oregon Wheat Foundation purchased a 57-acre block of land that had encompassed the two most-recent leases, and immediately leased the block to the Station for an annual cost of $150 per acre.

Administrators and Staff

It was already stated that David Stephens became the first Superintendent of the Pendleton Station, a position he also held at the Sherman Station. In 1928, he moved George Mitchell, one of his assistants at Moro, to become the Assistant Superintendent responsible for overseeing the establishment of experiments and the buildings and grounds at the Pendleton Station. Mitchell had worked with Stephens at Moro from 1922 to 1928. In 1938, when Stephen's resigned from his positions in Oregon and returned to USDA work in Washington, D.C., Mitchell became the Superintendent of the Pendleton Station and Merrill Oveson became the Superintendent of the Sherman Station. Ten years later the administrators at the two stations were switched. The switch was forced by a USDA initiative to invest more heavily into research and personnel at the Pendleton Station. However, the USDA included in that initiative a proviso that it would only do so if Oregon State College would agree to transfer Oveson to Pendleton to serve as the Superintendent. Oveson was therefore moved to Pendleton and Mitchell was moved back to Moro. Oveson retired in 1966 and was succeeded by Dr. Charles Rohde, a wheat breeder already serving the Station.

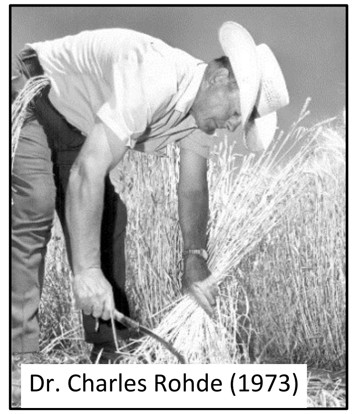
As stated earlier, the stations at Moro and Pendleton were once again linked as a single administrative unit on July 1, 1973. In 1973, the linkage also included the research center at Hermiston. The combined 3-station unit was designated as the Columbia Basin Agricultural Research Center (CBARC).

The first non-administrative staff member at the Pendleton Station was George Mitchell. He was an agronomist moved from the Sherman Station in 1928 to coordinate the development of the Pendleton Station, which was administered from the Sherman Station by David Stephens. Robert Webb, also from the Sherman Station, assisted Mitchell with the experimentation during the first two years, 1928-1930. In 1931, J. Foster Martin, a cereal breeder, also moved from the Sherman Station to the Pendleton Station. A third scientist, Joseph Belanger, made the move from the Sherman Station to the Pendleton Station in 1940. Many other scientists began arriving at the Pendleton Station during the 1940s and 1950s (Appendix 2).

About half of those scientists continued their employment for periods of five years or longer, including USDA scientists Carroll Ramage, Theodore Horning and Donald George, and OAES scientists Dr. Charles Rohde, Marr Waddoups and Dean Swan. The staffing levels continued to increase during the 1960s, with longer-term staff who arrived during that era including USDA scientists Drs. Robert Ramig and Ronald Rickman, and OAES scientist Dr. Donald Rydrych. Additionally, Dr. Arnold Appleby served in an interim capacity during a two-year vacancy in the Weed Science position at the Pendleton Station. Likewise, Dr. Orville Vogel (USDA, at Pullman) served in an interim capacity periodically during eight-years (1944-1951) in which there were repeated vacancies in the Wheat Breeding position at the Pendleton Station. A complete listing of OAES and USDA-Agricultural Research Service scientists is shown in Appendix 2. Scientists who arrived during the 1970s arrived after the establishment of the USDA's Columbia Plateau Conservation Research Center, in 1970, and the OAES's Columbia Basin Agricultural Research Center, in 1973. Key scientists at the two co-located centers will be indicated in following sections.


George Mitchell (1934)


Merrill Oveson (1953)


Dr. Charles Rohde (1973)

Operation of the Pendleton Station obviously required the assistance of many more people than are or could be acknowledged here. Many employees served important roles but the identity of individuals who served prior to about 1975 is no longer available.

Columbia Plateau Conservation Research Center (CPCRC): 1970

The CPCRC is co-located at the site of the Pendleton Station. The USDA had been present and actively engaged in research and leadership at the Pendleton Station since it was established in 1928. The early Federal scientists and support staff were mostly involved in research on cereal breeding, soil conservation, and efficiency of water use. Until 1970, all land was owned by Umatilla County and buildings were owned by the State of Oregon. Most scientists and staff members were employees of the USDA. The land-ownership and building complex was changed in 1970, when 10 acres were purchased from Umatilla County by the USDA, which erected new Federal buildings on a portion of that acreage.

Establishment Process (1959-1970)

A major expansion of soil and water research began in 1965 when, on October 21, the first session of the 89th Congress authorized $45,000 to start planning a proposed expansion of facilities at Pendleton, as had been recommended six years earlier in Senate Document 59, dated September 9, 1959. The 89th Congress' action was encouraged by a brochure submitted to Congress by the Oregon Wheat Commission, which acted on behalf of the Oregon Wheat Growers League, Oregon Wheat Commission, Oregon Association of Soil Conservation Districts, Washington Association of Wheat Growers, and Washington Association of Soil Conservation Districts. The undated 9-page brochure bore the title "*Research Facilities and Programs Needed to Solve Soil and Water Conservation Problems of the Northwest Wheat Producing Areas.*" The brochure stated that "*Senate Document No. 59 recommends a new office and laboratory building and related facilities at the Pendleton Branch Experiment Station to house an expanded soil and water conservation research program in the wheat-producing areas*." The objective was to "*develop information needed for effective field practices to conserve soil moisture, prevent erosion, and maintain good tilth on the Ritzville and Walla Walla soils in the Pacific Northwest*." It was also stated that some of

CPCRC Administrators: 1970-2020

Dr. Robert Ramig	1970-1972
Dr. Raymond Allmaras	1972-1984
Dr. Elizabeth Klepper	1985-1996
Dr. Dale Wilkins	1996-2003
Dr. Stephan L. Albrecht (interim)	2003-2004
Dr. Daniel Long	2004-2020
Dr. Stewart Wuest (interim)	2020

the work would be conducted at Moro, OR, Lind, WA, and on farmer's fields. The brochure concluded with the statement "*In 1960 the Senate Committee on Appropriations placed this item No. 22 on the list of 45 priority items. To date, items 1 through 15 have been provided which places the Pendleton item No. 7 on the present list. We strongly concur that this is a high priority item in the total facility needs described in Senate Document 59. We strongly urge the Department of Agriculture and the Congress to make these facilities available this year if possible*." Funding was promptly approved.

On October 25-30, 1965, Dr. Robert Ramig evaluated facilities at Twin Falls, ID, Sidney, MT, Mandan, ND, and Morris, MN. He prepared preliminary design criteria that were submitted on November 21, 1965. Additional information was submitted on December 9, 1965 and January 22, 1966. Since Federal buildings cannot be constructed on land not owned by the Federal government, 10 acres of land were deeded to the USDA from the 160 acres owned by Umatilla County and previously used by the OAES. The identification of the ceded land was determined at a conference in Pendleton on February 14, 1966. That conference included Dr. Robert Ramig (Pendleton Station), Mr. Merrill Oveson (Pendleton Station), Mr. Dean Muckel (Chief, Northwest Branch, USDA Soil and Water Conservation Research Division, Boise), Dr. Wilson Foote (Assistant Director, OAES, Corvallis), and Richard Coursen (Umatilla County Attorney). The Experiment Station approved a modification to the lease with Umatilla County, and acquired approval from the Oregon State Board of Higher Education. In 1966, the second session of the 89th Congress appropriated $371,000 for the construction of a laboratory. Mr. Wesley Korman, from Pendleton, was selected as the architect and engineer. He completed the plans in late 1968 after several prolonged reviews by U.S. General Services Administration.

Invitations to bid on the construction were called for on March 6, 1969. On July 1, a contract for $405,163 was awarded to William DeBauw, of Lake Oswego, OR. Construction activities began on July 22. Expansion of USDA staff also began immediately, with the transfer of Dr. Ronald Rickman to Pendleton from Kimberly, ID on August 26, 1969. The building was completed on May 11, 1970 and the new facility was named the Columbia Plateau Conservation Research Center. The building became occupied on August 25. About 210 guests were present at the official dedication on September 8, 1970. The dedication included administrators from the Oregon Wheat Commission, Pacific Northwest Associations of Soil and Water Conservation Districts, Wheat Growers Associations from the three Pacific Northwest states, Oregon State University, Washington State University and USDA – Agricultural Research Service's Soil and Water Conservation Research Division, and spokespersons from the East Oregonian newspaper and U.S. House of Representatives.

USDA-Agricultural Research Service Staff at Pendleton in 1971: (L to R) Dr. Ronald Rickman (Soil Scientist), Mrs. Marion Hibbard (Secretary), Dr. Robert Ramig (Soil Scientist and Director), Dr. Raymond Allmaras (Soil Scientist and Research Investigations Leader), Mr. Paul Rasmussen (Soil Scientist), and Mr. Lester Ekin (Research Assistant and Farmer)

Since about 2017, the USDA-ARS quit using the name Columbia Plateau Conservation Research Center. The current official designation for the USDA program at Pendleton is the Soil and Water Conservation Research Unit.

Administrators, Scientists and Staff

Dr. Robert Ramig was the first Director of the Columbia Plateau Conservation Research Center. Mr. Paul Rasmussen transferred to Pendleton from Prosser, WA on June 27, 1971, and Dr. Raymond Allmaras transferred to Pendleton from Morris, MN on August 22. By the end of 1971, Dr. Allmaras carried the title of 'Supervisory Soil Scientist and Research Investigations Leader' and Dr. Ramig carried the title of 'Soil Scientist and Director.' Dr. Allmaras became the lead administrator in 1972. He and subsequent leaders carried the title Research Investigations Leader.

In 1975, the USDA-ARS again initiated a major expansion of buildings and staff at the CPCRC. By 1976 the facility had added new buildings, equipment, and seven new employees. Key scientists who served at CPCRC (Appendix 2) included Soil Scientists (Dr. Robert Ramig, Dr. Raymond Allmaras, Dr. Ronald Rickman, Mr. Paul Rasmussen, Dr. Clyde Douglas, Dr. Joseph Pikul, Dr. Stewart Wuest and Dr. Hero Gollany), Agricultural Engineers (Dr. Clarence Johnson, Mr. Gerald George, Dr. Dale Wilkins and Dr. Mark Siemens), Soil Microbiologists (Dr. Harold Collins, Dr. Stephan Albrecht and Dr. Catherine Reardon), Hydrologists (Dr. John Zuzel and Dr. John Williams), Plant Physiologist (Dr. Elizabeth Klepper), Agronomist (Dr. Daniel Long), and Economist (Dr. Amos Bechtel).

These scientists were ably supported by many long-serving and dedicated technical and administrative staff. Of particular note are the contributions of Larry Baarstad, Amy Baker, Linda Baugh, Michael Bettis, Carol Brehaut, Maylene Bustard, Bob Correa, Phil Dailey, Les Ekin, Patricia Frank, Roger Goller, Richard Greenwalt, Daryl Haasch, Rebecca Hippe, Don Hulik, Marion Hibbard (a 40-year employee!), Tami Johlke, Mikayla Kelly, John McCallum, Doug Nelson, Grace (Freeman) Nelson, Jennifer Olson, Tracy Olson, Scott Oviatt, Wayne Polumsky, Chris Roager, Dave Robertson, Catherine Skirvin, Joe St. Clair, David Steele, Dr. John Sulik, Steve Umbarger, Sue Waldman, Sharon Wart, and Jean Wise.

Over a period of five decades, these USDA scientists and staff have been administered by the five administrators shown in the box, plus several scientists who served during short interim periods. Drs. Ramig and Allmaras were shown in the 1971 group photo. Drs. Klepper, Wilkins and Long are shown below. Dr. Long announced his intent to retire in 2020.

Columbia Basin Agricultural Research Center (CBARC): 1973

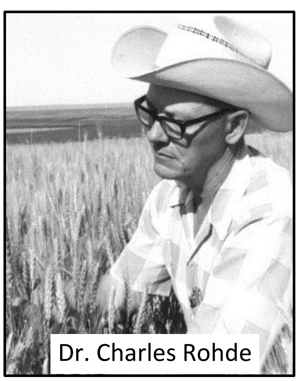
Establishment Process (1973)

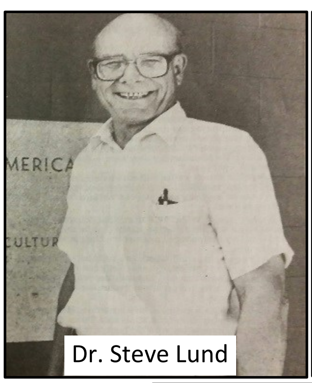
The CBARC was established on July 1, 1973, three years after the co-located CPCRC was established at the Pendleton Station. CBARC was a combined administrative unit that included the branch experiment stations at Moro, Pendleton and Hermiston. Documentation of reasoning for that decision is no longer available. However, it is the writer's speculation that the unexpected and sudden loss of 'corporate knowledge' at the Sherman Station was a likely stimulus for the decision to re-link the administrations of the Sherman and Pendleton stations. The Superintendent of the Sherman Station, Jack McDermid, died suddenly in January 1973. The timing of his passing coincided with the declining health of Clarence Mersinger, the long-time farm foreman for the Sherman Station. Mersinger formally retired in 1975 and passed away in December 1976 "*after a long illness.*" Simultaneously, Tom Davidson, the Superintendent of the Umatilla Branch Experiment Station, at Hermiston, was preparing for retirement after serving that location for 23 years. Dr. Charles Rohde was the then-current Superintendent of the Pendleton Station and was fully familiar with and participated in research at all three stations. The writer presumes that these circumstances led to the administrative linkage of the three branch experiment stations.

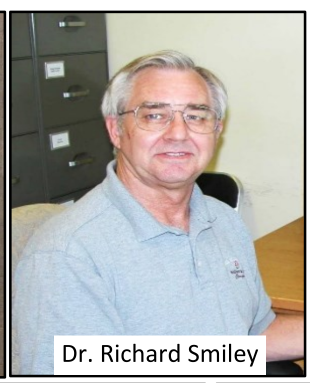
CBARC Administrators: 1973-2020	
Dr. Charles R. Rohde	1973-1975
Dr. Steve Lund	1975-1984
Mr. Mathias Kolding (interim)	1984-1985
Dr. Richard W. Smiley	1985-2000
Dr. Steven E. Petrie	2000-2013
Dr. Stephen Machado (interim)	2013-2014
Dr. Valtcho Jeliazkov	2014-2015
Ms. Mary K. Corp	2015-2020

Administrators, Scientists and Staff

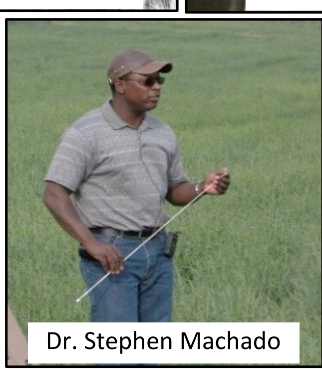
The first CBARC Superintendent was Dr. Charles Rohde, a wheat breeder who had served as the Superintendent of the Pendleton Station during the previous four years (Appendix 1). Rohde was an avid researcher and resigned from the administrative duties in 1975 so that he could resume and expand his wheat breeding research and extension activities. Dr. Steve Lund, a plant breeder at Rutgers University, became the next Superintendent of CBARC. During Lund's 10-year tenure, each of the three stations experienced deterioration caused by economic stresses and over-stretched administrative oversight. Upon Lund's retirement, in 1984, the Hermiston Station was again split away as an independent unit, leaving CBARC to consist of the Sherman and Pendleton Stations. Two scientists previously stationed at Pendleton became fully associated with the now-separated Hermiston Station, which became renamed the Hermiston


Dr. Charles Rohde


Dr. Steve Lund


Dr. Richard Smiley


Dr. Steve Petrie


Dr. Stephen Machado


Dr. Valtcho Jeliazkov


Mary Corp

Agricultural Research and Extension Center. Dr. Richard Smiley, a plant pathologist at Cornell University, became the CBARC Superintendent in 1985. After 16 years, in 2000, Smiley stepped down from administrative duties to focus more heavily on research and extension to understand and manage root diseases of field crops at CBARC for another 15 years.

In 2000, Dr. Steve Petrie became the CBARC Superintendent, after serving as an agronomist for Unocal Corporation and Martin Marietta Corporation. Shortly thereafter, the administrative title at all OAES branch stations was changed from Superintendent to Director. Petrie resigned and returned to the fertilizer industry in 2013. Dr. Stephen Machado, a cropping systems agronomist at CBARC, served as Interim Director for 1.5 years until Dr. Valtcho Jeliazkov was appointed Director in late 2014. Dr. Jeliazkov had been an agronomist and Superintendent of the University of Wyoming Research and Extension Center, at Sheridan. Ten months after arriving at Pendleton, Dr. Jeliazkov was transferred to a research and teaching position at Corvallis. Each of the administrators until that time were appointed to full-time positions at the station, with a portion of that time being allocated to administration. In late 2015, Ms. Mary Corp was appointed half-time Director of CBARC. At another location, she also continued as Staff Leader for the Umatilla County Extension Service and as Oregon Extension Service's Regional Administrator for the Columbia Plateau Region (Umatilla, Morrow and Gilliam counties). Corp announced her intent to retire in June 2020.

Key scientists who served for prolonged periods at CBARC (Appendix 2) included Cereal Breeders (Dr. Charles Rohde, Mr. Mathias Kolding, Dr. Steve Lund, and Dr. Pamela Zwer), Cereal Variety Test Coordinator (Dr. Ryan Graebner), Soil Scientists (Dr. Donald Wysocki and Dr. Steve Petrie), Agronomists (Mr. Vance Pumphrey, Mr. Darrel Maxwell, Dr. Thomas Chastain, Dr. William Payne, and Dr. Stephen Machado), Weed Scientists (Drs. Donald Rydrych, Daniel Ball and Judit Barroso Perez), and Plant Pathologists (Drs. Richard Smiley and Christina Hagerty).

The work of these scientists was supported by many long-serving and dedicated technical and administrative staff who made strong contributions to CBARC for many years. In particular, the author pays special tribute to Gloria Eidam, Secretary and Office Manager for 28 years (1975-2003), Karl Rhinhart, Farm Manager at the Pendleton Station for 33 years (1991-2017), and Erling Jacobsen, Farm Worker and then Farm Manager at the Sherman Station for 32 years (1986-2018). Other dedicated technical and clerical staff included Nancy All, Kyle Bender, Nathan Blake, Frank Ball, Larry Bennett, Dr. Julie Biddle, Scott Case, Dr. Chengci Chen, Bob Correa, Duane Davies, Kathleen Dumont, Sandra Easley, Sandra Frost, Gerald George, Jennifer Gourlie, Kyle Harrison, Matthew Hunt, Chris Humphreys, Milton Jones, Duncan Kroese, Wesley Locke, Dr. Dara Melanson, Karen Morrow, Sandra Ott, Lisa Patterson, Susan Philips, Larry Pritchett, Daisy Rudometkin, Jason Sheedy, Nick Sirovatka, Anthony Spence, Judy (Elliott) Skjelstad, David Sutherland, Debbie Sutor, Dr. Alison Thompson, Paul Thorgersen, Dr. Wakar Uddin, Kathleen Van Wagoner, Dr. Darrin Walenta, Kathy Ward, Alan Wernsing, Ruth Whittaker, Dr. Guiping Yan, and others.

***References*:**

Reports and Documents from the Sherman and Pendleton Stations (Appendices 1 - 11)

Letters sent to or from the Station Superintendents

Anon. 1909. Proceedings of the County Court in Connection with Purchase of Site for the Eastern Oregon Dry Farming Sub-Station. September 13, 1909. Sherman County, Oregon. 1 page.

Hall, W. E. 1959. *History of Wheat Varieties in Sherman County*. Oregon Agr. Exp. Station Unpublished Mimeo. 3 pages.

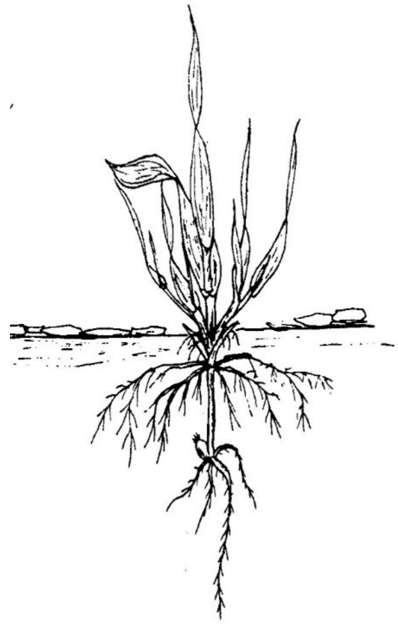
Scheuerman, R. D., and A. C. McGregor. 2013. *Harvest Heritage: Agricultural origins and heirloom crops of the Pacific Northwest*. Washington State University Press, Pullman. 186 pages.

Key Milestones at Moro

1989. First written statement of a ‘need for a dry-farming station’
1909. Location for a new station recommended to the Board of Regents
1910. Station was established: with buildings, equipment and teams
1911. First use of a gasoline engine on the Station
1911. First year in which true field research was conducted
1911. Crop rotation and tillage experiments were initiated
1912. First field tours; a farmer tour and an extension agent tour
1912. First research to control common bunt (stinking smut) of wheat
1913. First use of fungicide seed treatments
1913. First use of the rod weeder
1915. First purchase of an automobile; a Ford Model T Touring Car
1920. First use of synthetic nitrogen fertilizer
1921. Station was connected to the electric grid
1924. First research paper was published in a scientific journal
1926. First motorized farm truck was purchased; a Reliance
1926. Founding of the Oregon Wheat Growers League
1927. An electric motor was used to power a grain thresher
1927. The Ford car was used to power a grain thresher
1927. First report that at least two fungal species caused common bunt
1928. First tractor; a Holt 15 Caterpillar crawler-type tractor
1928. Administrations combined for Pendleton and Sherman Stations
1931. The first cereal breeder became located at the Station
1938. Administration of Sherman and Pendleton Stations were separated
1944. First use of a Massy-Harris self-propelled combine
1944. Departure of the last plant breeder to be located at the Station
1947. Superintendent’s house was destroyed by fire
1947. First use of chemical herbicides: 2,4-D
1948. Last use of horses for field work on the Station
1948. Construction of a new Superintendent’s house
1973. Hermiston Station was removed from administrative linkage of Sherman and Pendleton Stations, which were renamed the ‘Columbia Basin Agricultural Research Center’
1974. Original barn was sold and moved to a local farm
1985. Hermiston Station removed from CBARC administration
1985. First research emphasis on root diseases caused by soilborne fungi
1993. Establishment of the Sherman Station Endowment Fund
2005. First report of wheat yields being reduced by nematodes
2012. Construction of a new office building was completed
2013. Parcels of Experiment Station and County land were exchanged

Key Milestones at Pendleton

1909. First documented statement of a need for a dryland experiment farm in Umatilla County
1922. Umatilla County extension agent became cooperator to test wheat and barley varieties supplied by scientists from the Sherman Station
1925. Formal lobbying began for experiment station in Umatilla County
1927. Search began to identify a site for the new dryland station
1928. Joint funding was established between Umatilla County, State of Oregon, and USDA-BPI; administratively, the Pendleton Station became a satellite of the Sherman Station
1928. Land (160 acres) was purchased by Umatilla County and then leased to the Oregon Agricultural Experiment Station
1928. Purchases of equipment and teams began
1928. All land was plowed and left fallow during 1928, and then planted uniformly to winter wheat for harvest during 1929
1928. First winter wheat variety test was planted; it was small (three replicates of 10 entries)
1929. Constructed superintendent's house, implement shed & water well
1929. First automobile was purchased; a Chevrolet sedan
1929. First tractor; a Holt 15 Caterpillar crawler-type tractor
1930. Establishment of the first true research experiments
1931. First field tours; one for farmers and one for extension agents
1931. An office/laboratory building and a 3-car garage were constructed
1931. Initiation of the first soil moisture and nitrate research projects
1931. First plant breeder was assigned to the station
1932. Constructed a barn for animals and storage for seed and hay
1938. Sherman and Pendleton Stations were administratively separated
1938. Land (195 acres) near Cayuse was leased for weed research; the 'Morning Glory Research Farm' continued until 1948
1946. The Station's last work horse was sold
1948. A greenhouse and headhouse with a laboratory were constructed
1950. Three parcels of land were leased for research near Helix and Weston, bringing to 483 acres the land administered by the Pendleton Station; 160 owned + 323 leased
1951. Constructed a machine shed and plant breeding laboratory
1952. Constructed an apartment and walk-in cold rooms
1957. First 'extramural' funding for a research project; for weed research, from Dow Chemical
1969. USDA began major expansion of personnel and facilities
1970. A 10-acre block of Pendleton Station was transferred to USDA, for construction of new office & lab building, and for field research
1970. USDA staff, administration, budget and research became fully separated from the OAES
1973. Sherman, Pendleton and Hermiston Stations became linked as the 'Columbia Basin Agricultural Research Center.' They were administered by staff located at Pendleton.
1985. Hermiston Station was separated from CBARC
1985. First research on root diseases caused by soilborne pathogens
1991. A new greenhouse and headhouse were constructed
1994. Departure of the last plant breeder from the Station
1998 & 2002. Two pole-barns were constructed for storage
2009. Pendleton Station Endowment Fund was established
2004. A 37-acre parcel of land adjacent to the Station was leased
2014. An adjoining 17-acre parcel of land was added to the lease
2016. The original Superintendent's residence was demolished



Chapter 4 - Climate: Impacts and Challenges

As in all dryland agricultural pursuits, the amount and distribution of precipitation and the intensity and duration of cold or hot weather events have critical influences on planting, seedling establishment, plant development, and harvest operations.

Climates at the Stations

Formally, the climates at the dryland experiment stations are classified Interior Mediterranean with mild wet winters and dry hot summers (Crtichfield, 1966). In other climate-descriptive systems, the region is classified as mid-latitude semiarid, with relatively low rainfall intensities. Maximum winter rainfall intensity ranges up to 0.2 inch/hour, with a median of 0.03 inch/hour (Ramig, 1988).

The Sherman Station is located immediately southeast of Moro at coordinates 45º29' N and 120º43' W. The average elevation is 1,886 feet above sea level and the mean annual precipitation is 11.1 inches. Mean daily air temperature is 31 ºF during January and 66 ºC during July and August. The soil is a moderately deep (mostly >50 inch) Walla Walla silt loam that is well drained on a topography that varies from level to moderately steep (0-10 percent slope).

The Pendleton Station, now the home of two research centers, is located eight miles northeast of Pendleton at coordinates 45°43′ N and 119°37′ W. The average elevation is 1,510 feet above sea level and the mean annual precipitation is 16.3 inches. Mean daily air temperature is 32 ºF during January and 70 ºF during July and August. Soil is a moderately deep (mostly >40 inch) Walla Walla silt loam that is well drained on a relatively level topography (0-4 percent slope).

Nearly all precipitation at both locations occurs from late autumn (October) through spring (May). Dr. Bob Ramig evaluated precipitation records at both stations and reported the amounts received each month from 1938 to 1987 (Ramig, 1988). Ramig's summary was presented to assist farmers in making decisions whether to recrop, seed a drought-evading crop, or fallow to conserve more water for the next crop. Ramig then examined the variability of precipitation at these stations and at several off-station research sites (Ramig, 1989). He found the precipitation to approximately fit a normal curve over time, and he divided those frequencies into years that were 'normal, dry, very dry, wet or very wet.' At each location, about two-thirds of the years were found to occur in the 'normal' category with respect to long-term annual precipitation at that location.

Potential evaporation exceeds precipitation from March through October, causing small rainfalls during that period to be of little or no value to plants or to infiltration of water into the soil profile. Water from small rainfall events during late spring and summer is typically lost within two days by evaporation into the atmosphere. Nevertheless, those rainfall events are recorded as a portion of the annual rainfall. Weather variability is more critical at the lower-precipitation location (Sherman Station) than at the higher-precipitation location (Pendleton Station). Therefore, only the variability at the Sherman Station will be characterized in the following passages.

One of the initial cooperators with the Sherman Station was the Biophysical Investigations Branch of the USDA-BPI. Annual reports from the Station, from 1910 until 1973, provide detailed weather data for each year and, more importantly for this review, a very detailed descriptive summary of weather patterns relative to the productivity of the crops produced during each of those early years.

Weather stations were established at the Sherman Station in January of 1910, and at the Pendleton Station in late 1928. For the Sherman Station, there are still available many dozens of letters of communication between the Station Superintendent and the Biophysical Investigations Branch during the period from 1912 to 1920. These letters were focused on the 'proper' way to report weather records, such as the exact time to take readings at the weather station, how to calculate parameters not actually measured, and how to submit the data. At that time, this was a rapidly evolving field and new equipment was being introduced and fine-tuned. There was a high demand on the time and patience of the Station staff. For instance, the following was stated in a letter dated September 6, 1916: "*Your humidity records May 1 to July 30 have been sent in without the dew point and average daily vapor pressure being computed. You will please hereafter have this work done by the man who has the work in charge. To send in records incomplete as the ones referred to, more than doubles our work. It is for this reason that we ask you to co-operate in making it possible to have all the records in shape ….*" There were also time-consuming requests regarding such things as exploring the possibility of making and storing ice at the Branch Station. The Superintendent

(Dave Stephens) was also tasked with identifying a farm or town in Sherman County or Klickitat County where there would be no cumulus cloud cover during a total solar eclipse scheduled to occur in that area on June 8, 1918. They required that the location Stephens identified for staff of the U.S. Weather Bureau, Division of Solar Radiation Investigations, must be near lodging and at a place where there would be no clouds or dust caused by wind. Stephens provided attributes and detriments of every small town in the triangle from Arlington to The Dalles to Goldendale. Further examples of top-heavy administration of weather records at the Sherman Station are taken from a memo and warning, dated June 14, 1917, sent out by the Portland Forecast District of the USDA Weather Bureau: "*In order that the interests of the Government may be fully safeguarded …, you are advised that reports of observations by special meteorological observers …, or information that may be drawn from such reports, must be considered as purely Government information which must not under any circumstances be supplied or furnished to any other than the duly accredited representative of the Government…*"

With time, additional instruments were installed and, for various reasons, the site of the weather station was changed and the manner in which the data was presented was modified. For instance, the location of the weather station at Moro was changed on October 30, 1937, March 1, 1950, and March 31, 1957. Wind data from the site used from 1950 to 1957 had been significantly affected by trees and buildings. The change in 1957 was made because the new site would measure more wind, and presumably more accurately represent conditions at the experimental sites which were mostly at a higher elevation. The old and the new stations were both operated and monitored for comparative purposes during 1957. The weather station has remained at the same location from 1957 until the present (2020). The 1957 Sherman Station Annual Report includes two conversion factors based upon comparisons of measurements during 1957. One equates evaporation rates from the evaporation pan used before and after 1957, when both the location and type of pan were changed. The other conversion equates wind velocity reported before and after the change of location during 1957.

In 1959, the tables of climate data were presented on a crop-year basis for the first time. Previously, they had been presented on a calendar year basis. This change was made to place all climatic data for the entire crop of winter wheat into the same table. In 1969, several important changes were made in the weather recording. Soil thermometers were installed at 4- and 12-inch depths. A recording hydrothermograph was also installed to directly record humidity. Records also began to be taken of the maximum and minimum water temperatures in the evaporation tank. The time at which the recordings were made and entered into the records was changed from 5:00 p.m. to 8:00 a.m. These changes are important when interpreting weather data from the Sherman Station.

Examples of Historical Statements about the Weather

While it is beyond the scope of this writing to repeat details of the weather experienced at each Station each year, it is important to provide examples of those summaries to illustrate the difficulties faced in research as well as in commercial farming in low-precipitation environments such as at the Sherman Station. Research at the station was designed to examine tillage and cropping systems across years with highly variable weather patterns. That variability and its effect on crops was described in great detail in reports from the Sherman Station from 1910 until 1973. Abbreviated examples of those descriptions are reproduced from Annual Reports (Appendix 5) for the year indicated.

1911: The weather was very unfavorable. The spring was cold, windy and dry. The spring broke into an early summer that was very hot and dry. Many newly planted grasses and alfalfa failed to emerge, or died soon thereafter. The winter-sown crops suffered also.

1912: Unusually good weather conditions prevailed. A peculiar feature about the season was that land given comparatively poor tillage produced yields as high as land given thorough tillage. Plats given no cultivation other than plowing gave practically as high yields per acre as those on which the best known 'moisture conservation methods' were used.

1913: Poor stands of winter wheat occurred as a result of exceedingly adverse weather conditions during the fall of 1912. But 1913 was generally favorable for wheat production throughout eastern Oregon. Many farmers reseeded failing winter wheat fields to spring wheat. Temperatures remained cool through June and into mid-July, but suddenly turned hot in mid-July and continued hot for 10 days, causing many spring crops to suffer. Only the earliest maturing varieties of spring wheat yielded well, with yields as high as for the best winter wheats. Yields of corn and potato were poor.

1914: Weather conditions were about normal and nothing interfered to unduly influence any of the experimental work. Only the late-maturing spring grains suffered from the hot weather that occurred during early July.

1917: Weather conditions for the crop year of 1917 were unfavorable. Low rainfall prevented farmers from planting the usual acreage of winter wheat. Rains during early November were followed immediately by freezing weather that stopped all further farm work. Very little snow fell during the winter, resulting in some winter kill of some varieties of winter wheat. However, all the hardier Turkey varieties came through winter with good stands. All winter barleys were completely killed. In the spring, the soil had been moistened only to a depth of 18 inches. The spring was unusually dry, with no effective rainfall after May 24th, greatly limiting production of spring cereals.

1919: Plentiful rainfalls during September and early October of 1918 were favorable for planting winter cereals early. There was no winter injury. Soil was moist to a depth of three feet by late March. There was no excessively hot weather during the growing season. Yields of 35 to 40 bushels per acre in the varietal and tillage experiments during 1919 were the highest since the Station was established.

1920: Opening rains during the fall were excellent and farmers could begin planting winter wheat any time after September 11. But the winter of 1919-1920 was the coldest ever recorded at the Station. Fortunately, there was a covering of snow when the extremely cold weather (down to -20°F) occurred during the first half of December. There was no damage to the winter wheats.

1921: The weather was excellent, with early and plentiful rains, and a mild winter. By spring, the soil had been moistened to a depth of more than five feet, as compared to the more normal depth of three feet. Yields of winter wheat were the second highest since the Station was established, exceeded only by the yields during 1916.

1922: Weather conditions during the fall of 1921 and the spring of 1922 were very unfavorable for crop production. Most of the wheat planted during September did not emerge to produce uniform stands until early November. Heavy snowfall during mid-November, followed by a week of cold weather, then warm weather to melt the snow, then continuing low temperatures through December and January, all colluded to cause winter kill of some of the winter cereals, and runoff of water and soil in the early spring due to frozen soil. The spring was late and cold, with no rainfall occurring after April 1. Spring cereals received essentially no rainfall from the time of planting to time of harvest.

1923: Weather conditions were generally favorable for cereals. Moisture was not sufficient to germinate wheat before the first week of October. Extremely cold weather occurred during mid-December but a heavy snow pack protected the winter cereals. Grains yields were the highest ever at the Station, with the exception of the bumper crops achieved during 1916. As an anomaly, the winter wheat planted the latest was the highest yielding this year. This occurred because record rainfall during July came too late for most plantings but did favor the later-maturing wheats planted very late. This was a reversal of the usual findings during previous years for this experiment, caused by an unusual weather pattern.

1924: [Four pages of weather narrative in this report are fascinating.] The weather conditions during 1924 were unfavorable for crop production. The fall rains didn't begin until the end of September. The winter was mild, with cold weather only affecting the fall-sown spring grains. Wheat was lush after growing through the winter. But precipitation during the growing season, from March to July, was the lowest on record. The lush wheat rapidly exhausted the water in the soil profile. Yields of all grains were lower than usual. Corn plantings were a total failure. The total precipitation during calendar year 1924 was 8.2 inches, the lowest since the Station was established. The crop year precipitation, September 1 to August 31, was also the lowest on record; 7.7 inches. Only 0.9 inches fell during the growing season, March 1 to July 31, and all of it came in small amounts (<0.1 inch) that was of no benefit to the growing crops.

1925: September and October were too dry to germinate winter wheat. Considerable rain occurred in early November. Mid-December temperatures were unusually high, leading to seedling emergence just before the temperature suddenly dropped to 0°F and continued in that range for two weeks, with the lowest temperature being -11°F. There was no snow cover and the soil froze to a depth of greater than two feet. Not even one winter wheat plant survived on the Station. Except parts of Umatilla and Wasco counties, all fields in all Columbia Basin counties had to be totally reseeded to spring grains. Replanting occurred during late January and early February. Good weather during the spring growing season, and more than 2.2 inches of rain over a 5-day period in May, led to a productive year for the spring cereals and the replanted winter wheat.

1926: The weather was unfavorable for production of cereals. Many fields throughout the region were not harvested. Of the fields harvested, thousands of acres had yields of less than 10 bushels per acre. The wheat growth was good until mid-May, whereupon drought injury ruined much of the crop. There was no rain after May 4 until the grain ripened. The total rainfall was lower than average but the distribution of rainfall had an even more important effect on grain yields.

1928: The weather was conducive to early planting and there was no winter kill or late season drought. Yields were very good in 1928.

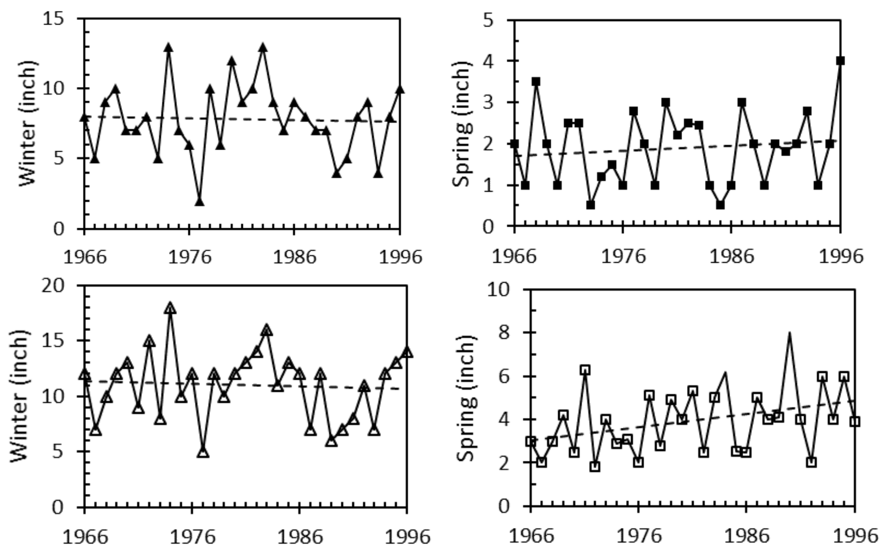
1933: The 1933 crop year was the fifth consecutive year with weather conditions unfavorable for crop growth. The autumn was favorable for planting but two unusually cold temperature periods, during December and February, both without snow cover, caused severe damage to winter wheat stands. The December period lasted for nine days and had a low temperature of 6°F below zero. All except the most winter-hardy varieties were completely killed. Most of the winter wheat trials were replanted on January 11 during a mild period. Another cold spell in February lasted for six days and had a low temperature of 12°F below zero. The winter wheats planted in January did not emerge until the first of April. Spring wheat trials were planted on March 31. A very late frost occurred on June 10; it was by far the latest frost date measured at the station. Total precipitation during the crop year was considerably below normal, and drought stress in all winter and spring varieties became evident soon after they started heading. Yields of all wheat, oat and pea crops were well below normal. Surviving spring wheat varieties yielded from 14 to 22 bushels per acre and surviving winter wheats yielded from 14 to 20 bushels per acre. The winter wheat yields have now averaged between 14 and 18 bushels per acre for the fifth consecutive year, compared to no previous two consecutive years with yields below 25 bushels per acre, a maximum of 51 bushels per acre in 1916, and a 20-year mean of 27 bushels per acre.

1937: Weather conditions during the fall of 1936 were unfavorable for planting winter wheat for the eighth consecutive year. Winter wheat was planted during late October into dry soil. The first precipitation did not come until late December, when snow fell on unfrozen soil and was laid down in very uneven drifts. The drifts remained until late February. The winter wheat did not emerge until mid-March and the stands were thin and non-uniform. The spring was very dry, when rains occurred during mid-June, too late for the already droughty winter wheat but very helpful for some of the spring wheat, but also causing rank, weak straw in the late-maturing spring wheats. The crop season precipitation was exactly equal to the long-term average, but the distribution of the precipitation events was unfavorable. Due to the uneven snow coverage, the winter wheat stands were highly variable, with plants varying from 1-foot to 2.5-feet high. Due to the drought during 1936, spring wheat was substituted for winter wheat in the rotation trials.

During the late 1980s Dr. John Zuzel, a USDA hydrologist at Pendleton, released a computer program that provided the average weather data for any location in eastern Oregon or Washington (Zuzel and Karow, 1988). The program 'Weather Wizard' could report average weather data for periods ranging from 10 days to one year. The prediction included maximum and minimum air temperatures, rainfall, and heat units (growing-degree days). Each estimate was specific to the site selected by the individual making the inquiry. While these estimates were not considered forecasts, they did provide historically based averages that could be useful for planning purposes. There were no similar predictive programs available at the time the Weather Wizard programs were released for Oregon in 1988 and for Washington in 1990. The Weather Wizard was a pioneering achievement of the CPCRC, and was intended to be used by farmers, ranchers, extension personnel, and others whose planning process required the use of weather considerations. Today, of course, such estimates of weather patterns are commonly available on a myriad of web sites.

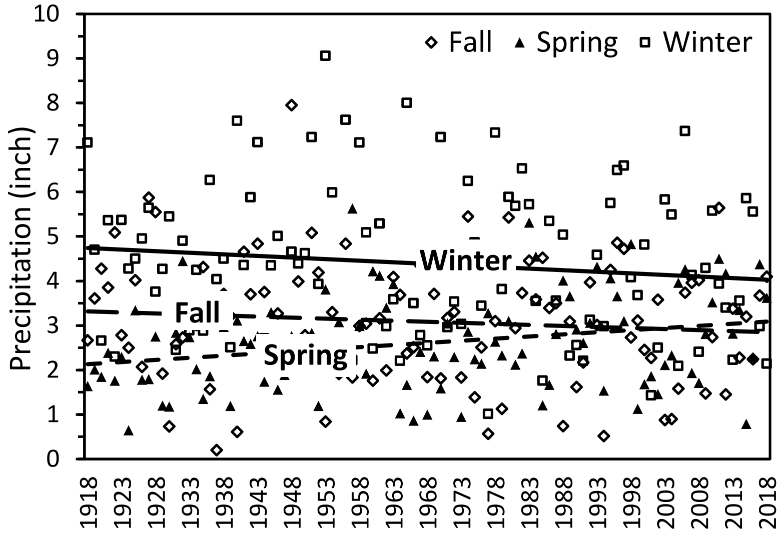
Changes in Seasonal Precipitation Pattern

Paul Rasmussen and Dr. Bill Payne evaluated 30-year seasonal precipitation trends at the Pendleton and Sherman Stations (Rasmussen et al., 1988). They reported that winter precipitation, from September 1 through March 31, varied from season to season but the average remained relatively steady from 1966 through 1996. In contrast, spring rainfall, from April 1 through June 30, generally increased over that same 30-year period. Those relationships are shown in the following figures. Rasmussen et al. (1998) also presented data to show that yields of winter wheat after fallow remained relatively steady, from 68 to 75 bushels/acre for each of the three decades studied. In contrast, yields of winter wheat following dry peas increased in proportion to the spring precipitation; 49, 63 and 71 bushels/acre for each successive decade. Also, yields of dry pea increased each decade: 1125, 1431 and 1590 pounds/acre for the three decades. They also showed increasing yields of annual spring wheat over the three decades; 31, 43 and 55 bushels/acre. The same trend occurred for annual spring barley. Rasmussen et al. (1998) concluded that shifting seasonal precipitation distinctly closed the gap between yields of annual spring crops and winter wheat produced after fallow.



Thirty-years trends for seasonal precipitation during winter (September 1 – March 31) and spring (April 1 – June 30) at the Sherman (left column) and Pendleton (right column) Stations. Data were redrawn from Rasmussen et al. (1998) [see Appendix 4].

In 2018, Dr. Stephen Machado re-summarized seasonal precipitation over the past century at the Sherman Station. The following chart shows a slight decline in precipitation during both the fall and winter, and an increase in precipitation during the spring. The crossover period in which trend lines for spring precipitation became equal to fall precipitation at the Sherman Station occurred in about 2002. After that time, precipitation during the spring has generally exceeded that in the fall. The U.S. National Climate Assessment, published in 2014 (https://www.globalchange.gov/nca4), indicated that the PNW regional average temperature increased by about 2 ºF and precipitation increased by about 10 percent over the past century. These trends are of great importance to agriculture and to the interpretation of research results. Some experiments conducted three or more decades ago may no longer be relevant to agriculture today, mostly because of differences in total and seasonal relationships between precipitation and temperature.



Seasonal precipitation at the Sherman Station during the past century. Note the declining trends for autumn and winter precipitation, increasing trend for rainfall during spring, and a crossover in amount of spring and autumn rainfall in about 2002. Unpublished, from Dr. Stephen Machado.

***References*:**

Annual Reports of the Sherman and Pendleton Stations (Appendices 5 and 6)

Critchfield, H. J. 1998. General Climatology, 4th edition. Prentice-Hall, Englewood Cliffs, NJ. 464 pages.

Letters sent to or from the Station Superintendents

Ramig, R. E. 1988. Rainfall at the Pendleton and Moro experiment stations. Pages 62-67 in: Oregon Agr. Exp. Station Special Report 827. Oregon State University, Corvallis.

Ramig, R. E. 1989. Variability in crop-year precipitation. Pages 92-100 in: Oregon Agr. Exp. Station Special Report 840. Oregon State University, Corvallis.

Rasmussen, P. E., W. A. Payne, and R. H. Goller, 1998. Thirty-year rainfall trends and implications for crop yield in the Columbia Plateau. Pages 35-40 in: Oregon Agr. Exp. Station Special Report 989. Oregon State University, Corvallis.

Chapter 5 - Research Scope and Locations

It is not possible to study some production problems on station lands due to an absence of certain important weeds or diseases, or a limited variability of climate, tillage systems, soil properties, or availability of sufficient land. Scientists often establish experiments at off-station locations. Recent experimentation by the station scientists has been conducted throughout Oregon, Washington, Idaho and Montana, and in other regions of the U.S.

Scope of Research

Experiments performed at the Sherman and Pendleton Stations have included long-term as well as short-term studies. Long-term studies examine experimental variables that remain relatively unchanged for periods of five or more years. Tillage management and crop rotation experiments are examples of studies that are conducted over longer time periods. Plant breeding and screening of herbicides and fungicides are examples of short-term experiments that typically consist of trials with different treatments or field sites or locations each year. Experimental systems with each of these durations have been conducted at on-station and off-station sites.

Research by scientists at the stations has been conducted under the same vagaries of weather that were faced by farmers. However, when soils have been particularly dry, especially during the autumn, some experimental areas have received pre-plant irrigation to assure rapid germination of seeds and establishment of the crop. Moreover, research specific to irrigated lands has long been a minor component of work by scientists at these 'dryland' research stations. For instance, Mr. Jack McDermid conducted five successive years of testing with potential alternative crops at two irrigated locations in Sherman County during the late 1960s. Likewise, two scientists were hired at the Pendleton Station to conduct research on irrigated crops. Mr. Roland Schwanke was an Assistant Professor for Irrigated Crops and worked on irrigated production systems in the typically 'dryland' regions of eastern Umatilla County during 1968 and 1969. When he resigned in early 1970, Mr. F. Vance Pumphrey was immediately transferred from the Eastern Oregon Experiment Station at Union, Oregon. Pumphrey's initial appointment at the Pendleton Station was to conduct research on irrigated crops in the region. He later diversified his research to include problems occurring on non-irrigated crops. Many other scientists at the Pendleton Station have conducted a portion of their research in irrigated fields across northeast and north-central Oregon, south-central Washington, southern Idaho, and at the branch experiment stations at Hermiston, Union, Madras, Klamath Falls and Ontario.

Much of the research emphasis has been directed toward conservation of soil, retention of water, provision of adequate plant nutrition, breeding and selection of the most productive or high-quality crop varieties, developing machinery to perform the required tasks, and developing methods to control weeds and diseases. However, emphasis has also been given to studies of different planting methods, types of fertilizers and their application methods, effects of geography and soils and climates on grain yield, and methods for managing crop residues. Likewise, the wisdom of planting wheat in a wheat-fallow rotation rather than annually has been questioned from time to time. Another question to which the scientists responded regarded production practices for other market classes of wheat at times when soft-white winter wheat provides low profitability. There have also been questions about the most efficient way to convert perennial pastures into wheat production. Production of forage crops or the use of grain by-products as feedstuffs in animal rations was another interest of growers. These and other questions were studied by scientists at the Sherman and Pendleton Stations.

The objectives and sometimes the results of these experiments are summarized in topical chapters that follow. This chapter and the following chapter (Chapter 6) are general introductions to some of the experiments and locations where long-term research was conducted.

On-station Long-term Research

The experiments included some that were performed for many decades and had only minor changes to tillage methods and to input variables over the life of the experiment. Long-term experiments were essential to identify how soils, crop yields, and pests changed over time. Data were reported in great detail and were summarized repeatedly in annual reports prepared at the Stations until 2009 (Appendices 4-6). Specialty topics such as crop breeding, crop variety testing, weed control, and monitoring of soil moisture and nitrogen in field experiments were typically summarized in separate volumes of the annual reports prior to 1976, and then reported periodically in a summary format until 2009. No summary reports from the stations have been published since 2009.

Annual reports are still available for research conducted at the Sherman Station and Pendleton Station from their time of inception until 1970. Some duplicity of testing is evident and was inevitable as scientists from the Sherman Station were initially responsible for testing across the region, including Umatilla County. Those scientists then began to be transferred from the Sherman Station to the Pendleton Station in 1928. The early workers faced the same agricultural issues in both locations and, except for differences in amount of rainfall, elevation and temperature, the agricultural challenges were similar in each region. Identical or similar experiments were established at each station and in each county, allowing the scientists to factor weather variables into their experimentation. This multi-site practice became an expected aspect of the research during the 1950s, when individual research programs at Pendleton became responsible for testing at both locations. This opportunity for multi-site comparisons was further formalized in 1973, when the two dryland branch experiment stations became linked as the Columbia Basin Agricultural Research Center (CBARC). Interestingly, the 1974 Annual Report included only information from the Pendleton Station, with no mention of the identical trials that some of those scientists also conducted at the Sherman Station and other sites throughout the region. The annual report for 1975 is the first to actually integrate the testing at Pendleton and Moro, but in a different format than during the earlier years.

Dave Stephens (1915) commonly stated that "*the beneficial results obtained from experiment station work cannot adequately be measured in terms of money.*" Nevertheless, he also commonly estimated the financial benefits provided to the agricultural communities as a direct result of the research being performed at the Sherman Station. In 1915, only five years after the Sherman Station was established, Stephens published a table which estimated that the experiments conducted during the first three years of testing at the Sherman Station had already provided "*a total annual gain to the farmers of these five counties of $1,775,250.*" That figure, based on values during 1915, included calculations for Sherman, Wasco, Gilliam, Morrow and Wheeler counties. Stephens also stated that he felt the results were equally applicable in Umatilla County. Today, we would also suggest that the results were applicable to Klickitat County and to some other low-rainfall wheat production areas of Washington. Stephens' stated that the first varieties released by the Sherman Station were producing at least four bushels per acre more than the standard commercial varieties at that time. He calculated that the improved production resulted in the production of an extra 1.2 million bushels on 300,000 acres, with wheat being sold for 75¢ per bushel. In 1944, Dave Stephens summarized results of conservation practices that had been studied at five Pacific Northwest experiment stations, including those at Moro and Pendleton (Stephens, 1944).

Oveson (1940) summarized 30 years of research at the Sherman Station and stated that the Station served a farming area of 1,250,000 acres distributed over six counties in which wheat production is the major crop. In addition to the experimental research conducted at the Station, outlying cereal variety nurseries had also been conducted at two locations in Jefferson County, three in Gilliam County, one in Wasco County, and two in Sherman County. He went on to state that yields of new wheat varieties developed at the Station up to that point had enabled farmers in eastern Oregon to increase their yield by 15 percent, representing an increase of 1.5 million bushels valued at 70¢ per bushel, or at least $1 million annually.

Oveson and Besse (1967) published a 20-page summary of research at the Pendleton Station during its first four decades. They stated that, before the station was established, soil testing had been done to compare virgin grassland with land that had been cropped for 50 years. The upper foot of cultivated soils contained 28 percent less organic matter than grassland soils, equating to a difference in 27,600 pounds of organic matter per acre. Similar results had previously led to establishment of the Sherman Station. The realization of this problem caused wheat growers to seek funds from the Oregon Legislature and the USDA to conduct research for the purpose of developing a farming system that would maintain the native fertility of the land and reduce soil erosion. Oveson and Besse's overview was for research seeking to attain that objective. Pumphrey and Rasmussen (1995) extended that summary to include 25 years of additional research conducted after the report by Oveson and Besse.

The three summaries of research cited in the foregoing paragraphs were brief statements of accomplishments but provided little detail regarding experimental methods or results. As stated in the introduction, the intent of the present treatise is to include greater detail in describing the huge amount of expertise and effort that has characterized research at these locations, and has contributed to economic development in the region.

More recently, Douglas et al. (1992) categorized regions of the Inland Pacific Northwest according to six Agronomic Zones defined by similarities in temperature, precipitation, and soil depth. Smiley (1992) used the maps for those zones and local knowledge of agriculture in the region to calculate the cultivated land area represented by each experiment station in the Pacific Northwest. The stations at Moro (Zones 4/5) and Lind, Washington (Zone 5) represent 61 percent of the cultivated dryland acreage in Oregon and Washington, amounting to 5.8 million acres. Those two stations are far more representative of rainfed dryland acreage than the 19 percent of dryland wheat represented by the stations at Pendleton (Zones 2/3) and at Pullman, Washington and Moscow, Idaho (Zone 2). Likewise, the 14 percent of acreage that is irrigated is served mostly by research centers at Hermiston and Prosser, Washington (Zone 6).

The first experiments at the Sherman and Pendleton Stations included testing of crops and varieties, crop rotations, depth and date of plowing, and methods to conduct tillage for efficient management of summer fallow. The scientists and their staff took detailed notes to record many types of measurements and observations in almost all treatments of every experiment. Their annual reports (Appendices 5 and 6) contained most of the raw data as well as summaries and interpretations, in economic as well as in agronomic terms. It is beyond the scope of this review to reevaluate or to restate the tremendous amount of information contained in those annual reports. For brevity, in later chapters, the author chose to briefly describe the experiments and then jump to a time when the experiments were being terminated to highlight significant contributions made during the course of that research.

Most notable among the long-term experiments are several at Pendleton that are considered to be of historical significance. Those on-going trials include several that were established during 1930 and have undergone minimal change to the present time. Those trials are explained in greater detail in Chapter 6.

Off-Station Long-term Research

Experiments similar to those performed on the stations were often also conducted at other locations. This began during the earliest years of the station's existence. During some years during the past two decades as much as 75 percent of the total research effort by Pendleton-based scientists has been conducted at off-station locations.

Off-station sites are selected for several reasons. Some are selected to represent a broader range of climatic conditions than are available at Moro and Pendleton. Others are selected because of on-going problems with weeds or diseases that cannot be easily replicated on the stations. Others are selected because the experiments are too large to be accommodated on the already heavily used research stations. Some off-station sites are selected for political reasons, to focus on farms for which the farmers serve on boards of funding organizations, or are otherwise politically active.

Most off-station research was of short duration, often for only one or two years. It was conducted on land donated or rented by a cooperating farmer or another of the agricultural research centers, such as at Hermiston, Madras, Union, Burns, Klamath Falls and Ontario, in Oregon, and at Lind and Prosser, in Washington.

Longer-term off-station experiments that were expected to continue relatively unchanged for at least five years required much higher levels of logistics, resources and funding than were necessary for shorter-term off-station experiments. More than ten off-station long-term experiments were coordinated from the Pendleton Station. Examples of major sites are as follows.

Umatilla Indian Agency (1938-1948)

The "Umatilla County Weed Experiment Station" was the first of the off-station long-term experiments in eastern Oregon. It consisted of 158 acres located five miles east of the Pendleton Station and one mile north of Cayuse, on land leased from the Umatilla Indian Agency for 50-cents per acre for a minimum period of 10 years. A severe infestation of field bindweed (morning glory) had been greatly reducing yields of winter wheat across an entire field for at least the previous 30 years. The Station was therefore also known as the 'Morning Glory Farm.'

The primary objective of experiments was to identify methods to control or eradicate field bindweed, which was causing a great reduction in wheat yields and could not be controlled by any tillage practices attempted up to that time. Moreover, the intent was to achieve the objective without using the effective, but dangerously explosive herbicide, sodium chlorate, which was the chemical of choice against field bindweed at that time.

Establishment and operation of the Weed Experiment Station was complex. The station was established under an agreement between Mr. Walter Holt, Umatilla County Extension Agent, and Omar L. Babcock, Superintendent of the Umatilla Indian Agency. With the assistance of the Umatilla County Court (Judge Carl Chambers), Holt and Babcock developed and signed a Memorandum of Agreement stipulating a lease of 195 acres for a 5-year period, with a minimum renewal period of an additional five years. The lease rate was to be renegotiated upon renewal. The county enlisted a commitment from a local farmer (Mr. Clarence Tubbs) to farm whatever land that was not used for experimentation, using farming practices to be recommended by the extension service. Mr. Tubbs was permitted to sell the grain produced on the land that he farmed.

Since the extension service had no equipment with which to conduct the research, they asked George Mitchell, Superintendent of the Pendleton Station, to supervise the research and to transport State-owned equipment to the site to conduct the tillage, planting, sampling, and harvesting operations on the 40-acres used for experiments. Another Memorandum of Understanding was therefore consummated between the U.S. Office of Indian Affairs, Umatilla County Court, OAES, and OES. However, the USDA-BPI denied a request that Mitchell and other Federal personnel stationed at Pendleton conduct any work on the new project. The USDA instructed that no Federal labor, equipment or funds could be used for the project. Mitchell and his employees therefore needed to do the work at the Weed Experiment Station on their own time during evenings, weekends and holidays. They also had to use their personal vehicles because the only 'work' vehicles at the Pendleton Station were a Federal pickup and truck. Subsequently, Mitchell was required to repeatedly report in detail to administrators in Washington, D.C. all of the hours, dates and specific times of each day on which he or other personnel worked at the Weed Experiment Station. Mitchell was also required to report the license number of each vehicle used for travel to and from the site.

The Indian Agency provided $300 toward the purchase of a small International Farmall 20 wheel tractor and a duckfoot cultivator, and to construct a closed shed to house the farm equipment and a sturdy fence to restrain large animals (horses, cattle and elk) from gaining access to the property. That $300 was also intended to purchase seed and fertilizer for the 40-acre experimental area. The county paid the remaining expenses for those items, with a provision that the Agricultural Experiment Station reimburse the county within two years, upon which time the ownership for the equipment would be transferred to the Pendleton Station.

Plots were large, replicated, and farmed with field-size equipment. Annual field tours were conducted in the same manner as at other experiment stations. When the time arrived for the 5-year lease to be renewed, there were new administrators for the Umatilla County Extension Service, Umatilla County Court, Office of Indian Affairs (Washington, D.C.), Umatilla Indian Agency, OAES (Corvallis), and the Oregon Extension Service (Corvallis). George Mitchell, Superintendent of the Pendleton Station, was the lone person who had been involved with the original lease. Negotiation of the renewal was not simple or rapid. Because there had been a great increase in productivity of wheat at the site during the past five years, the Umatilla Indian Agency initially demanded a 6-fold increase in the lease rate and a portion of the harvest proceeds, without any Agency contribution to the input expense. These issues were ultimately resolved by the new administrators.

King 'Pilot' Farm (1949-1962)

Merrill Oveson leased a 75-acre field on the Lester King Farm as a low-rainfall site to test a wide variety of tillage practices for preparing and maintaining fallow. The King Farm was located west of Helix and had 12.5 inches of mean annual precipitation. Topography ranged from steep slopes to relatively level flats. The field was managed as a winter wheat-fallow rotation. All plots were large enough (66 × 132 feet) for the use of commercial-scale equipment, which was transported to and from the site from the Pendleton Station. The primary objective of experiments at the King Farm was to identify or modify equipment capable of managing high amounts of wheat residue without burning the stubble. Oveson, Ted Horning and others evaluated the efficiency of numerous methods and types of equipment, types and rates and timings of nitrogen application,

Hauling a combine to an off-station site and plantings of conservation grasses. They measured wheat productivity, net profit, water storage, nitrate concentrations, weed control and other factors. Summaries of experiments at the King Farm are provided in Chapters 13 and 15.

Hill 'Pilot' Farm (1950-1959)

Merrill Oveson leased a 75-acre field on the James Hill Farm, also located west of Helix, as a replicate for wheat-fallow experiments described for the nearby King Farm. All objectives, practices and treatments were identical. The mean annual precipitation at this site was 11.7 inches. The only difference for experiments at the King and Hill farms was that the crop year was offset to make it possible for scientists to gather data each year for the in-crop phase as well as for the fallow phase of the wheat-fallow rotation. The King and Hill Pilot Farms were also used to examine the performance and stand longevity for 33 combinations of conservation grasses and legumes which were planted either alone or in combinations. The steepest slopes were planted to Whitmar Beardless Wheatgrass to make observations regarding soil erosion.

Crow 'Pilot' Farm (1950-1964)

Merrill Oveson leased a 75-acre field on the Samuel Crow Farm to examine the benefits of crop rotations for improving soil quality and for producing annual crops in a spring wheat-green pea rotation. The Crow Farm was located southwest of Weston and received 16.4 inches of mean annual rainfall. The initial rotations consisted of 3-, 4- and 5-year sequences to incorporate sweet clover as a green manure crop. Oveson quickly identified an economic disadvantage for green manure crops, spring wheat crops, and legume companion crops in spring wheat. He therefore terminated the use of those experimental variables during 1955. The two green manure rotations were replaced by a winter wheat-fallow rotation and a continuous winter wheat treatment. Spring wheat in the other three treatments was replaced with winter wheat, and a commercial fertilizer variable was incorporated into the rotation scheme. Results are summarized in Chapter 12 and elsewhere.

Kirk 'Pilot' Farm (1977-1987)

Dr. Raymond Allmaras leased five acres of land at the Harold Kirk Farm to measure soil erosion on a slope of the Blue Mountains, nine miles east of the Pendleton Station. The USDA's Kirk Natural Erosion Research Site was on a 16 percent slope at 2,400 feet elevation, and had a mean annual precipitation of 21 inches. This site was used to gain a deeper understanding of processes that influence erosion caused by rain on frozen or snow-covered land, and erosion caused by seepage of water through soil. A primary objective of research at the Kirk site was collect data to refine the Universal Soil Loss Equation (USLE) so that it would become more accurate in the Pacific Northwest. That research contributed to development of an improved model called the Revised Universal Soil Loss Equation (RUSLE).

Drs. Clarence Johnson, Raymond Allmaras and Joe Pikul collected data to develop technology for predicting erosion, improving designs of diversions, terraces and sediment basins, and developing better tillage and management practices. Six 13.3 × 110 foot plots were managed as pairs of continuous cultivated fallow, or in each phase of a winter wheat-spring crop rotation. The usual spring crop was peas but spring wheat was also used occasionally. All plots were plowed during the spring, enabling comparisons of three types of cover during winters; winter wheat seedlings, winter wheat stubble, and fallow. Measurements were made of weather variables, moisture content of the soil profile, runoff rate and amount of soil lost, nitrate and phosphorus in the runoff, and particle size distribution of the soil lost. Results are summarized in Chapter 17.

Hauling a seed drill to an off-station site (1981)

Gilliland and Shaw Farms (1993-1998)

Dr. Dan Ball and colleagues were donated 20-acres of land on each of two farms near Pilot Rock. The intent was to examine conservation tillage systems and weed management. The field on the Ted Gilliland Farm was located east of Pilot Rock and received 11.5 inches of mean annual rainfall. Experiments were performed from 1993 through 1998. The field on the Jeff Shaw Farm was located north of Pilot Rock and also received 11.5 inches of precipitation. Experiments were performed from 1994 through 1999. All objectives, practices and treatments were identical at the two locations. The two farms were used as replicate locations with offset cropping phases each year.

The goal was to examine different conservation tillage cropping systems for controlling downy brome, conserving soil and water, and increasing the economic viability. Specific practices included identification of the best protocols to apply fertilizers, till the soil, and establish crop stands in various conservation treatments. Experimental treatments were performed with commercial-size equipment provided jointly by the land owner and the Pendleton Station. Four replicates of seven treatments were established using half-acre plots. A summary of the treatments and findings by Drs. Ball, Richard Smiley, Don Wysocki, and Umatilla County Extension Agent, Mike Stoltz, are provided in Chapter 21.

Hennings Farm (1995-2007)

Winter wheat production in the intermediate to low rainfall areas has continued to rely upon a winter wheat-fallow rotation to provide sufficient soil moisture to raise an economically viable wheat crop. Compared to other production systems, the winter wheat-fallow rotation has continued to be the most profitable and the least variable from year to year. Nevertheless, especially with cultivated fallow, that production system has often left the soil surface open to wind and water erosion, and has been subject to many problems with weeds and diseases. Computer models estimated that no-till spring crops could reduce soil erosion susceptibility by 95 percent.

Dr. Frank Young, USDA-ARS at Pullman, WA, assembled a team to conduct a 12-year experiment with alternative spring cropping systems. The team represented the host farmer and scientists from 10 disciplines including an agronomist, weed scientist, plant pathologist, entomologist, soil chemist, soil microbiologist, wheat breeder, barley breeder, soil physicist, and agricultural economist. The scientists were from five agencies and three states. Dr. Richard Smiley, from the Pendleton Station, served as the project's plant pathologist.

The site selected for this research was 25 acres of donated land on the Curtis Hennings Farm near Ralston, which is south of Ritzville in Adams County, WA. The mean annual precipitation at the Henning Farm is 11.5 inches. The initial goal was to determine if planting spring crops could protect the soil while also increasing farm profitability by reducing losses from winter annual weeds and root diseases. However, there was also a question as to whether no-till farming might lead to a shift to a new suite of weed and disease problems. A summary of research at this site is provided in Chapters 12 and 20.

Jepsen Farm (1999-2008)

The Monsanto Company and cooperating farmers conducted a number of cropping systems demonstrations in the low rainfall regions of the Inland Pacific Northwest during the early 2000s. One demonstration was named the 'Center of Sustainability' and was located on 30 acres of donated land on the Bill Jepsen Farm, east of Heppner. After five years, in 2003, that demonstration was incorporated into crop rotation research that Dr. Stephen Machado was establishing at the Sherman Station. During the next five years, the Center of Sustainability included nine cropping systems that were similar to those at the Sherman Station. Mr. Jepsen managed the crops and harvests. Other agronomic, weed and disease data was collected by scientists from the Pendleton Station, including Drs. Stephen Machado, Dan Ball, and Richard Smiley.

Center of Sustainability Demonstration – William Jepsen Farm – Heppner – 2004

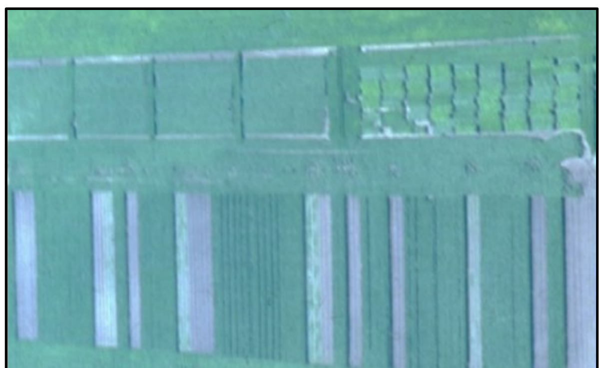
The Center of Sustainability site was unique because it received similar crop-year precipitation as occurs at the Sherman Station (about 11 inches), but it had shallower soil (2 feet depth) than the Sherman Station site (>4 feet). That contrast made it possible to determine the influence of soil depth on the cropping systems. Treatments at the Jepsen Farm were not replicated but they were large (80 × 900 feet) and were managed using the grower's commercial equipment. It became possible to split individual plots to collect samples and make measurements in two to four more pseudo-replications across different slope aspects. Results are summarized in Chapters 12 and 20.

Reese Farm (1972-2018)

The Leon and Dorothy Reese Farm was the longest lease for off-station research; 46 years. It was located between Echo and Pendleton, where the leased land allowed the USDA-ARS to expand experimental research into the low precipitation zone, where the average annual precipitation is 11.4 inches. Approximately 30 acres was utilized because it met experimental needs regarding soil type, meteorological exposure, and availability of irritation water under ARS control. Leon Reese assisted scientists by plowing border areas of field experiments, spraying and cultivating certain plot areas, and providing straw for certain experiments. Electrical power was available for operating instruments in the field and a telephone line was installed for remote data transmission. In 1990, budget and research needs dictated that the lease be reduced from 30 to 2 acres. In 1999, the lease was changed to 10 acres situated near the original block. In 2003, the boundaries were adjusted to 14.2 acres and in 2013, an individual field comprising 26 acres of dry crop land was added to provide space for a large-plot cropping systems trial with cereals and oilseeds, and for collecting site-specific grain protein and yield data. The lease was terminated after the harvest during 2018. Experiments at the Reese Farm were directed by Drs. Raymond Allmaras, Bob Ramig, Stewart Wuest, Daniel Long, and Catherine Reardon.

Cuthbert Farm (1986-1992)

Dr. Richard Smiley selected two acres of an irrigated field north of La Grande to identify crop rotations and nematicides that could be used to reverse a yield decline caused primarily by the cereal cyst nematode. The John Cuthbert Farm was located in an area that received 18.9 inches of mean annual precipitation. All tillage, fertilizing, planting, spraying and harvest operations were conducted by transporting equipment from the Pendleton Station. The primary experiment was a crop rotation studied over a six-year period, using 11 replicated treatments of plots measuring 16 × 100 foot. Smaller short-term pesticide and variety trials were also located at that site. Results are summarized in Chapter 20.


Experiments at Cuthbert Farm - 1991

Reeder Farm (1998-2008)

The USDA-ARS leased a 40-acre site on the Dr. Clinton Reeder Farm to study watershed hydrology over larger landscapes managed with different tillage operations. Dr. John Williams managed a 40-acre block as a 'drainage experiment' for 10 years, during which he established and maintained experimental rotations for eight years, from 2001 to 2008. The block was divided into two facing watersheds separated by a swale. No-till practices were used on a 26-acre south-facing drainage with a maximum slope of 30 percent. The no-till drainage was divided into four plots managed as a 4-year rotation of winter wheat, spring-planted pea, winter wheat, and chemical fallow. Two complete rotations occurred on all four plots over the 8-year period. A facing 14-acre drainage was conventionally tilled (moldboard plow) and had a maximum slope of 20 percent. It was managed uniformly as a winter wheat-cultivated fallow for the first four years (2001-2004) and was then divided so that plots with each phase of the rotation could occur each year. Dr. Williams and colleagues measured components of weather, soil water content in soil profiles, water and sediment discharge rates and volumes, ground cover and crop yield. The experiment was described in Williams et al. (2014) and in other reports.

The site at the Reeder Farm was compared with two smaller landscapes on other nearby farms. A 4-acre site, called the 'hillslope experiment,' was conducted on a steep (23 percent), north-facing slope at the Jim Duff Farm. Crops were grown without tillage for seven years (1998-2005) and minimum tillage for three years (2006-2008). The slope was divided along its central break and studies were made of 'watersheds' on either side of the slope. A 5-acre site, called the 'draw experiment,' was located on the John Adams Farm. It consisted of a shallow draw (slopes of <4 percent) on which no-till and minimum-tillage were compared on opposite sides of the draw. Williams conducted replicated plots with 4-year rotation treatments similar to those described for the no-till rotations on the 'drainage experiment' at the Reeder Farm. Results of these experiments are summarized in Chapter 17.

***References*:**

Annual Reports of the Sherman and Pendleton Stations (Appendices 5 and 6)

Letters sent to or from the Station Superintendents

Douglas, C. L., Jr., R. W. Rickman, B. L. Klepper, J. F. Zuzel, and D. J. Wysocki. 1992. Agroclimatic zones for dryland winter wheat producing areas of Idaho, Washington, and Oregon. Northwest Science 66:26-34.

Oveson, M. M. 1940. Examples of Accomplishments and Projects at the Sherman Branch of the Oregon Agricultural Experiment Station in Cooperation with the U.S. Bureau of Plant Industry from 1909 to 1940. An Unpublished Station Summary. 8 pages.

Oveson, M. M., and R. S. Besse. 1967. The Pendleton Experiment Station: Its development, program and accomplishments … 1928 to 1966. Oregon Agricultural Experiment Station Special Report 233. Corvallis, OR. 20 pp.

Pumphrey, F. V., and P. E. Rasmussen. 1995. The Pendleton Agricultural Research Center, 1967-1992. Oregon Agricultural Experiment Station Special Report 950. 38 pages.

Smiley, R. W. 1992. Estimate of cultivated acres for agronomic zones in the Pacific Northwest. Pages 86-87 in: Oregon Agr. Exp. Station Special Report 894. Oregon State University, Corvallis.

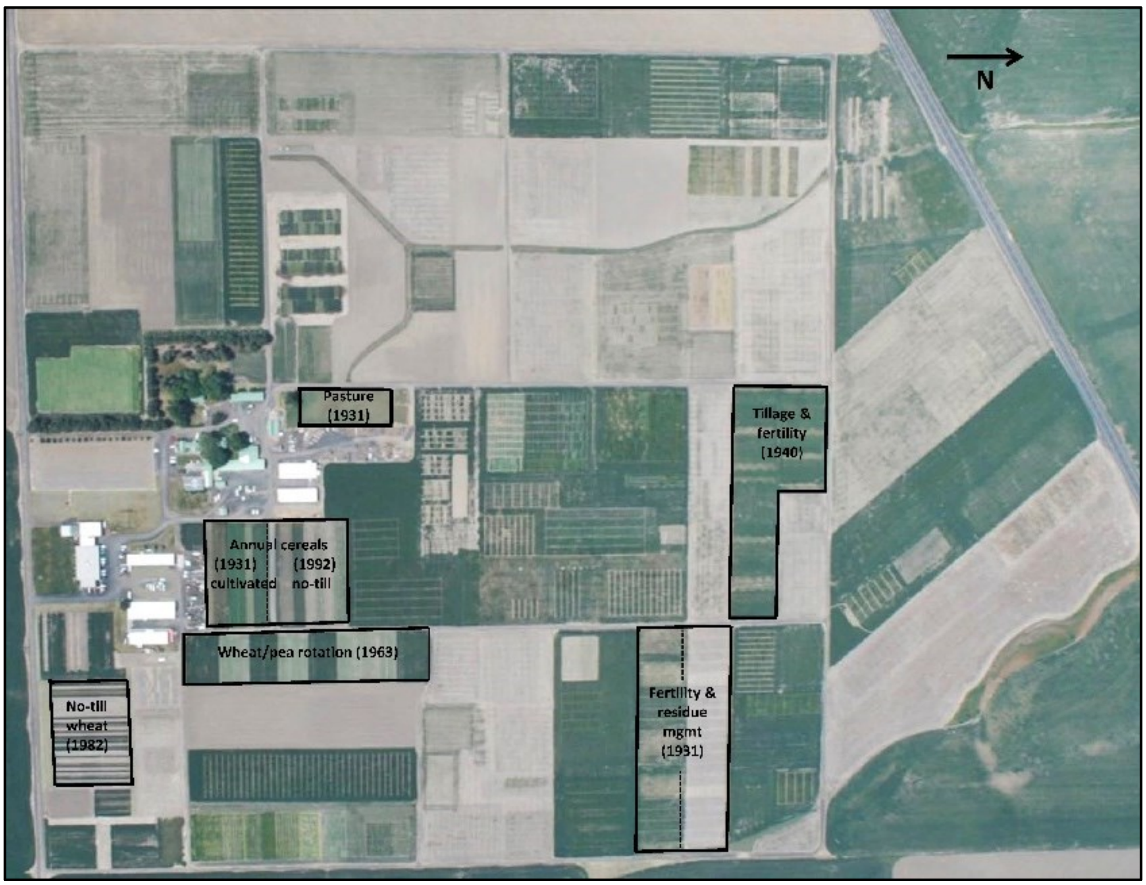
Stephens, D. E. 1915. Report of the Eastern Oregon Dry-Farming Branch Experiment Station, Moro, Oregon: 1913-14. Oregon Agricultural College Experiment Station. (no number assigned). 42 pages.

Stephens, D. E. 1944. Effect of tillage and cropping practices on runoff, erosion, and crop yields in the wheat growing areas of Washington, Idaho, and Oregon. Pages 1-105 in D. E. Stephens, Conservation Practices on Wheat Lands of the Pacific Northwest. U.S.D.A. Soil Conservation Service, Pacific Coast Region ·· Seven. Washington, D.C. 125 pages.

Williams, J. D., S. B. Wuest, and D. S. Long. 2014. Soil and water conservation in the Pacific Northwest through no-tillage and intensified crop rotations. Journal of Soil and Water Conservation 69:495-504.

Chapter 6 - Current Experiments of Historical Importance at Pendleton

Seven long-term experiments at the Pendleton Station were established by scientists employed by the USDA and have been administered and managed since inception by both the USDA and Oregon State University. One experiment is thought to be the oldest cultivated agricultural experiment west of the Mississippi River. Because of the historical importance of these experiments, and of the potential danger for local day-to-day administrators or managers to make ill-conceived changes to the experiments, the management of these experiments has been overseen by a Regional Oversight Committee since 1987. Members of the committee include locally-based OSU and USDA scientists and unit administrators, Directors of the OAES (Corvallis) and the Pacific West Area of the USDA-Agricultural Research Service (Albany, CA), and senior scientists who represent on-campus crop and soil science departments at Oregon State University, Washington State University and the University of Idaho. The Committee recommends modifications to improve usefulness and current applicability, and provides guidelines for soil, plant and water measurements that would minimize detrimental effects and maintain the integrity of future experiments. It is also the purview of the Committee to determine when or if an experiment is to be terminated, or a treatment is to be considered of insufficient benefit to warrant continued maintenance.



Locations of historically important experiments at the Pendleton Station

A summary of these historically important experiments was published by Rasmussen et al. (1989). The overview shown on the aerial photograph and in the table is followed by a more detailed description of each experiment. Collectively, these experiments occupy 13 percent of the experimental land at the Pendleton Station.

Following the summary by Rasmussen et al., the Rockefeller Foundation selected the crop residue experiment as the representative for international research on sustainability of wheat-fallow agriculture in semi-temperate environments. The Rockefeller study included long-term experiments selected to represent agricultural sustainability in other climates, including England, India, The Philippines, and eastern U.S. Each representative experiment was analyzed and results were summarized as individual chapters of the book "*Agricultural Sustainability: Economic, Environmental and Statistical Considerations*". The most important and provocative finding from the study at Pendleton was that measures of soil health increased as measures of the farmer's economic sustainability decreased (Duff et al., 1995). The inverse relationship identified at that time became an issue for much discussion as society continued to exert emphasis for the adoption of no-till and related practices that intended to increase the health and agronomic sustainability of agricultural soils.

Key features of seven historically-important experiments at the Pendleton Station

Name	Estab-lished	Age in years[1]	Till-age[2]	Rotation, Crops or management[3]	Treat-ments[4]	Repli-cates
Crop residue	1931	89	CT	WW-F	9F	2
Perennial pasture	1931	89	NT	PG	none	1
Annual cultivated cereals						
Winter wheat	1932	89	CT	WW	2F	1
Spring wheat	1977	43	CT	SW	2F	1
Spring barley	1982	38	CT	SB	2F	1
Annual no-till cereals	1997	23	NT	WW, SW & SB	3C, 2F	1
Tillage-fertility	1940	80	CT	WW-F	3T, 6F	3
Wheat-pea rotation	1963	57	CT	WW-SP	2C, 4T	4
No-till wheat	1982	38	NT	WW-F	5F	4

[1] Age in the year 2020.
[2] Tillage systems are either cultivate (CT) or not cultivated (no-till; NT).
[3] Crops and management include winter wheat (WW), spring wheat (SW), spring barley (SB), spring pea (SP), perennial grasses (PG), and cultivated fallow (F).
[4] Number of treatments for each major variable of crop (C), fertility or other input (F), or type of tillage (T).

During 2018, four of these long-term experiments were selected for inclusion in a new National Soil Health Initiative. Samples will be collected from the experiments for contrast and comparison with the sustainability of other experiments across the U.S.

Crop Residue

This is the most comprehensive of the oldest experiments. It was established in 1931 by David Stephens and George Mitchell. There are currently nine treatments that include different rates of nitrogen fertilizer, burning or not burning the wheat stubble, application of all inputs using animal manure or pea vines, or not applying any inputs at all since 1931. The experiment is a 2-year rotation of winter wheat and cultivated fallow, using the moldboard plow as the implement for primary tillage.

Treatments in the crop residue experiment are as follows:

1. (discontinued)
2. application of 40 lb N/acre before each wheat crop and the wheat stubble is burned in the spring (40 N + burn)
3. application of 80 lb N/acre before each wheat crop and the wheat stubble is burned in the spring (80 N + burn)
4. application of 40 lb N/acre before each wheat crop and stubble is incorporated into soil (40 N)
5. application of 80 lb N/acre before each wheat crop and stubble is incorporated into soil (80 N)
6. no added fertilizer since 1931 and the stubble is burned during the fall (FB)
7. no added fertilizer since 1931 and the stubble is burned during the spring (SB)
8. application of cow manure several days before soil and stubble are plowed (manure)
9. application of pea vines several days before soil and stubble are plowed (pea)
10. no added fertilizer since 1931 and the stubble is incorporated into soil (0 N)

The experiment has only had two major revisions since it was established in 1931. Those changes are shown in the table. The experiment contains duplicate, offset rotation phases that allows a crop to be harvested each year. Each phase consists of nine treatments replicated two times. In plots where the stubble is burned, that activity is performed in late September (fall burn) or in late-April or early-May (spring burn).

Key features of the long-term crop residue experiment at the Pendleton Station

No.[1]	Organic-N addition	1931 to 1966 Residue treatment[2]	1931 to 1966 N rate[3] (lb/ac/crop)	1967 to 1978 Residue treatment	1967 to 1978 N rate (lb/ac/crop)	1979 to present Residue treatment	1979 to present N rate (lb/ac/crop)
1	--	--	--	--	--	--	--
2	--	FD	0	NB	40	SB	40
3	--	SD	0	NB	80	SB	80
4	--	NB	30	NB	40	NB	40
5	--	NB	30	NB	80	NB	80
6	--	FB	0	FB	0	FB	0
7	--	SB	0	SB	0	SB	0
8	Manure[4]	NB	0	NB	0	NB	0
9	Pea vines[5]	NB	0	NB	0	NB	0
10		NB	0	NB	0	NB	0

[1]Treatment 1 was terminated earlier. Treatments #2-10 have been continued since 1931.

[2]Residue treatment: FD = fall disk, SD = spring disk, NB = no burning of stubble, FB = burn stubble in the fall, SB = burn stubble in the spring.

[3]Inorganic fertilizer applied during early October of the crop year, before winter wheat is planted.

[4]Manure = 10 tons/acre/crop (wet weight); 47.5% dry matter, 1557 lb C and 130 lb N/ac/crop, applied in spring of the fallow year, a few days before soil is plowed.

[5]Pea vines = 1 ton/acre/crop (field weight); 88.4% dry matter, 740 lb C and 34 lb N/ac/crop, applied in spring of the fallow year, a few days before soil is plowed.

Dr. Bill Payne spreading manure

Burned stubble treatments

Pea hay ready to be spread

All treatments are plowed in late spring after the residue amendments have been added or the stubble has been burned. Repeated secondary tillages with a rod-weeder are used to conserve moisture and control weeds during fallow. Herbicides are used in the fall or early spring to control downy brome and volunteer wheat before the soil is plowed. Herbicides are also applied during wheat crop growth to control broadleaf weeds. Each plot is 38 × 132 feet. The winter wheat variety Rex M-1 was grown from 1931 to 1966 and modern semi-dwarf varieties have been grown since that time. Nitrogen fertilizer was applied as ammonium nitrate broadcasted onto the soil surface from 1967 to 1988, and as urea-ammonium nitrate banded 6-inches deep with 10-inch shank spacing from 1989 to present.

Lister furrows have been installed each fall between plots to channel runoff water out of the experiment rather than being left to run onto adjacent plots. This process was initiated in 1989 because the burn plots began to have lower infiltration rates and greater surface runoff than that in plots where residue is incorporated. The furrows are dug along plot boundaries in both the wheat and stubble phases. The furrows are removed in late March and seeded to spring wheat to prevent moisture and nitrate buildup between plots.

Crop yields are measured annually and soil samples are collected for chemical and physical analyses at 10-year intervals. Local scientists and also scientists from other states and nations have made innumerable samplings to define differences among treatments for a wide array of parameters associated with soil chemistry, soil physics, soil microbiology, weed density, and wheat diseases.

This experiment was once selected as the global representative to define agricultural sustainability in temperate semi-arid climates (Duff et al., 1995). Results of on-going studies are shown in Chapter 15 and elsewhere.

Perennial Pasture

This pasture was originally established in 1931 by George Mitchell. The pasture contains no experimental variables and is currently used to approximate a near-virgin grassland, and as a base-line for evaluating changes in other experiments. It is 150 × 369 feet and is dissected by a drainage. The pasture received limited grazing from 1931 until 1985, after which time the vegetation was clipped once or twice during summer growth. It was periodically reseeded with selections of introduced grasses, and has received very limited and infrequent application of fertilizer and irrigation. The dominant grass species is bluebunch wheatgrass with lesser amounts of tall fescue and several grass weed species.

Annual Cereals (cultivated)

An experiment to determine the best method for preparing a seed bed for continuous production of cereals was established by George Mitchell and Dave Stephens in 1929. While there have been numerous changes, the plots have always been planted to a cereal crop each year since 1929.

Initially, the same plots were planted each year to winter wheat, spring wheat, winter barley, or spring barley. In 1931, after the third crop of spring wheat and second crop of winter wheat, it was already clear that plowing the field during the fall was the best way to prepare a seed bed for each of the crops. Plowing during the fall produced an average across crops of 1,013 lb/acre. The one-way disk during the fall produced an average of 742 lb/acre, and disking during spring, for the spring crops, averaged 1,014 lb/acre.

The experiment was therefore modified in 1931, with a 284 × 304 foot block cropped annually to winter wheat, and an adjacent 132 × 304 foot block cropped annually to spring wheat. Each block was divided into eight 38 × 132 foot fertilizer treatments, including a no fertilizer control, and two timings of application for sodium nitrate, ammonium sulfate, or a complete fertilizer (analysis of 7-8-2). The experiment was altered again in 1932, 1943 1952 and 1960. The eight plots received no fertilizer from 1932 until 1943, different rates of nitrogen (0 to 150 lb N/acre/year) from 1943 to 1951, and no fertilizer from 1952 to 1959 for winter wheat and from 1954 to 1959 for spring wheat. The two blocks began to be fertilized uniformly with nitrogen in 1960; 70 lb N/acre for winter wheat and 74 lb/acre for spring wheat.

The entire site was modified in 1977. The southern 66 × 304 feet of the winter wheat block was abandoned to provide room for an equipment storage area. The spring wheat site was abandoned, and spring wheat was then grown on the north 132 × 304 feet of the winter wheat experiment. The spring wheat block was divided in half in 1982, with the south 66 × 304 feet thereafter cropped to spring barley. The present experiment now consists of three 66 × 304 feet sections cropped to winter wheat, spring barley, and spring wheat, each of which are grown every year on the same blocks.

The application rate was unified to 80 lb N/acre for all blocks from 1977 to 1992. In 1993, a 12 × 284 foot strip in the winter wheat and spring wheat blocks was designated for termination of fertilizer application, while the remaining 54 × 284 foot strip in each block continues to receive 80 lb N/acre before each crop was planted. The same adjustment was made to the spring barley block during 1994. Also, the experiment was periodically treated with phosphorus and sulfur fertilizers since 1982.

Those blocks have been moldboard plowed (inversion tillage) just prior to planting each crop, from 1929 until the present time. Recently, these cultivated cereal monocultures have been planted with a John Deere 8300 double-disk drill with 6.8-inch row spacing. Both mechanical and chemical weed control practices are used. Pesticides are applied as needed to control weeds, insects and diseases.

Key features of the cultivated annual cereals experiment at Pendleton

Time period	Crop[1]	Variables	N applied (lb/acre)
1931-1942	WW,SW	none	none
1943-1951	WW,SW	N rate	0-150[2]
1952-1959	WW,SW	none	none
1960-1976	WW,SW	none	none
1977-1981	WW,SW	none	none
1982-1995	WW,SW,SB	none	80
1996 to present	WW,SW,SB	N rate	0 & 80

[1] Crops include winter wheat (AW), spring wheat (AS), or spring barley (AB).

[2] Eight strips had varying N rates applied across the blocks of winter and spring wheat.

Grain yield and test weight are determined by dividing the original eight nitrogen treatments in each crop block into four 66 × 76 foot sections that correspond to the initial fertility plots (1+2, 3+4, 5+6, and 7+8). Each of those 24 sections are harvested separately. Yields are measured by collecting bundle samples as well as by harvesting the blocks with a combine. Measurements are made of grain yield and test weight, kernel weight, harvest index, heads/ft^2, spikelets/head, kernels/head, and grain protein. The experiment currently serves as a cereal monoculture baseline for comparing other crop rotations that are based upon the use of the moldboard plow for primary tillage.

Annual Cereals (no-till)

This experiment was established in 1997 by Paul Rasmussen and Dr. Richard Smiley. The field was in a winter wheat-cultivated fallow rotation before this no-till experiment was established. A no-till (direct-seeded) annual winter wheat, annual spring wheat, and annual spring barley experiment was established adjacent to the older (since 1929) cultivated continuous cereal experiment describe earlier. As with the original experiment, the cereal blocks are not replicated. Also, in the newer experiment, the most practical, generally recommended methods and equipment available to growers are used. Recently, the no-till monocultures have been planted with a John Deere 1560 disk drill with 7.5-inch row spacing. Fertilizer is applied to the majority of the three cereals but, as with the original experiment, a strip of each block is not fertilized. Where applied, the fertilizer application rate is 90 lb N/acre for the spring cereals and 100 lb N/acre for the winter wheat. Pesticides are applied as on the older cultivated annual cereals experiment.

Tillage-Fertility

This experiment was established in 1940 by George Mitchell and Joseph Belanger. There were major revisions to treatment protocols in 1952, 1962 and 1988. The rotation is a rotation of winter wheat and cultivated fallow. There were initially two phases to allow a crop to be harvested each year, but one phase was terminated and there has been a harvest every other year since that time.

The experiment contains three replicates of three tillage treatments and six nitrogen application rate treatments. Tillage treatments included moldboard plow (at 9-inch depth, burying 95 percent of the crop residue), offset disk (at 6-inch depth, burying 60 percent of the residue), and 30-cm subsurface sweeps (at 6-inch depth, burying 35 percent of the residue). Nitrogen is applied one to two weeks before seeding. It was applied as a surface broadcast of ammonium sulfate (21-0-0-24S) from 1941 to 1962, surface broadcast of ammonium nitrate (34-0-0) from 1963 to 1988, and banding of urea-ammonium nitrate (32-0-0) since 1989, at 6-inch depth and 10-inch row spacing. The six nitrogen application treatments have varied over time.

Plots are 18 × 132 feet. Primary tillage occurs during April and secondary tillage and other cultural operations are the same for all primary tillage treatments. Plots are smoothed with a field cultivator and harrow following primary tillage. They are then rod weeded four to five times between April and October to control weeds and maintain seed zone moisture. Nitrogen is applied in early October and winter wheat is planted during mid-October. Herbicides are also applied uniformly but mainly to control winter annual grass weeds such as downy brome that become problematic in plots where there is an abundance of residue on the soil surface.

Key features of the tillage-fertility experiment at the Pendleton Station

Fertility sub-treatment		Nitrogen rate (lb N/acre/crop)			
No.	S history	1941-1952	1953-1962	1963-1988	1989-present
1	No	0	0	40	0
2	Yes	10	30	40	40
3	No	0	0	80	80
4	Yes	10	30	80	80
5	Yes	10	30	120	120
6	Yes	10	30	160	160

Routine measurements include grain yield, grain test weight, straw yield, and grain and straw nitrogen content. This experiment has also been noted for at least three decades as an excellent resource for studies of soil acidification caused by application of nitrogen fertilizer. Soil pH has become much lower in plots receiving the higher rates of application, as compared to plots receiving the lowest rate of nitrogen. This is discussed further in Chapter 15.

Wheat-Pea Rotation

This is the only remaining long-term rotation of winter wheat and a food legume. It was established in 1963 by Merrill Oveson and Dr. Robert Ramig. The experimental treatments were modified in 1972, 1976 and 1989. The 2-year rotation of winter wheat and dry processing pea contains four replicate blocks of each crop. There are eight blocks because each crop phase occurs each year. Within each block there are four tillage treatments of plots that are 24 × 120 feet. Tillage intensity ranges from maximal- to minimal-inversion of crop residue. The current tillage treatments are chisel plow in fall, moldboard plow in fall, moldboard plow in spring, and no-tillage.

Key features of the wheat-pea rotation experiment at the Pendleton Station

Treatment		Primary tillage	
No.	Identification	Wheat stubble	Pea vines
1	Max Tillage	Chisel (fall)	Disk/chisel (fall)
2	Fall Tillage	Plow (fall)	Plow (fall)
3	Spring Tillage	Plow (spring)	Plow (spring)
4	Min Tillage	No-till	No-till

Semi-dwarf soft white winter wheat is planted after October 10 whenever soil moisture is sufficient for seed germination and seedling establishment. Wheat is planted with a double-disk drill with 7-inch row spacing. Peas are seeded in late March or early April, and harvested in June or July. For the first 26 years, fresh-green processing peas were harvested by transporting the vines to a stationary pea viner. The type of pea grown was changed to dry-edible seed pea in 1989. Since 1989, a portable combine has been used to shell the dry peas directly in the plots, which leaves the pea vine residue on the soil surface. The vine residue is redistributed for uniformity, and the vine yield and nutrient content are determined.

From 1963 to 1988, wheat received 40 to 80 lb N/acre as ammonium nitrate (34-0-0) broadcast before seeding. In 1989 and 1990, each wheat plot received 20 lb N/acre as 16-20-0-14S). In crop year 1991-1992, one half of each plot received 80 lb N/acre and the other half received no additional nitrogen. Nitrogen application was reversed in 1993-1994, with the half receiving nitrogen for the previous wheat crop receiving no additional nitrogen two years later. This rotation of nitrogen fertilizer application was continued, to allow an evaluation of nitrogen needs of wheat in a wheat/legume rotation. Peas receive 20 lb N/acre as either ammonium sulfate (21-0-0-24S) or ammonium phosphate-sulfate (16-20-0-14S) broadcast onto the soil surface before planting every pea crop. The east half (a 60-foot-wide band) of the experiment received 1,800 lb of lime/acre in 1976. The western edges (24 × 24 feet) of some plots were fumigated with methyl bromide in the early 1980s.

This experiment has been shown to contain greater microbial diversity than the wheat-fallow long-term experiments at Pendleton.

No-till Wheat

This experiment was established in 1982 by Paul Rasmussen and Drs. Robert Ramig and Raymond Allmaras. The experiment was established to evaluate nitrogen fertilizer effects on crop yield and soil quality under no-till conditions. It was modified in 1983, 1988 and 1997. Previously, the field was managed as a cultivated winter wheat-fallow rotation, generally with some kind of primary tillage and secondary tillage operations for controlling weeds and maintaining moisture at seed zone depth during the fallow period. There are four replicates of 10 treatments, with each plot being 8 × 100 feet. The original treatments consisted of two sets of five nitrogen rates (see the table) banded below the seed and 100 lb N/acre broadcast onto the soil surface. The treatments either had the wheat stubble burned or the stubble was incorporated by tillage. From 1983 until 1988 the experiment was cropped annually in a winter wheat-spring wheat rotation. In 1989 the experiment was changed to a winter wheat-fallow rotation, the burn variable was terminated, and a date of planting variable was superimposed over the previous burn treatments. In 1993 the broadcast fertilizer application was terminated and the nitrogen rates were adjusted to align with those in other long-term experiments. The date of planting variable was terminated in 1997 and the experiment was revised such that odd-numbered plots were cropped in odd-numbered harvest years and even-numbered plots harvested in even-numbered years. Crop yields were therefore collected annually since 1997. The experiment is managed without tillage. Herbicides are used to control weeds in both fallow and wheat crops.

Key features of the long-term no-till wheat experiment at the Pendleton Station

	1982-1988		1990-1992		1994-1996		1997-present
Treat-ment No.	N rate[1] (lb/ac)	Stubble burned	N rate (lb/ac)	Planting time	N rate (lb/ac)	Planting time	N rate (lb/ac/ crop year)
1	0	No	0	Sep	0	Sep	0
2	0	Yes	0	Oct	0	Oct	0
3	50	No	50	Sep	40	Sep	40
4	50	Yes	50	Oct	40	Oct	40
5	100	No	100	Sep	80	Sep	80
6	100	Yes	100	Oct	80	Oct	80
7	150	No	150	Sep	160	Sep	160
8	150	Yes	150	Oct	160	Oct	160
9	100bc	No	100bc	Sep	120	Sep	120
10	100bc	Yes	100bc	Oct	120	Oct	120

[1] Fertilizer was broadcast where indicated (bc); all other nitrogen applications were banded 2-inches below the seed at the time of planting.

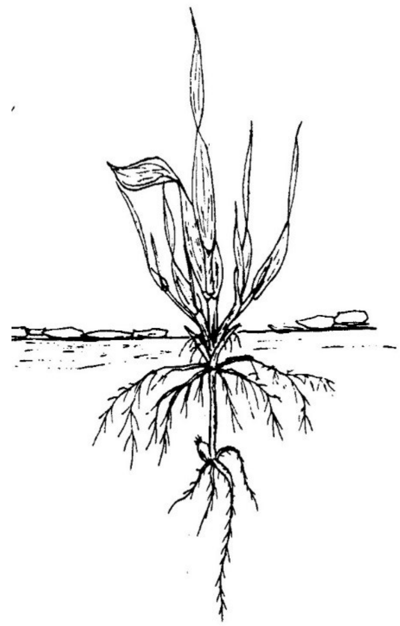
***References*:**

Annual Reports of the Pendleton Station (Appendix 6)

Letters sent to or from the Station Superintendents

Duff, B., P. E. Rasmussen, and R. W. Smiley. 1995. Wheat-fallow systems in the semi-arid regions of Pacific NW America. Pages 85-111. In: Agricultural Sustainability: Economic, Environmental and Statistical Considerations (V. Barnett, R. Payne and R. Steiner, editors). John Wiley & Sons, London. 266 pages.

Rasmussen, P. E., H. P. Collins, and R. W. Smiley. 1989. Long-term management effects on soil productivity and crop yield in semi-arid regions of eastern Oregon. Oregon Agricultural Experiment Station Bulletin 675. 57 pages.



Chapter 7 - Cereal Crop Breeding and Testing

Research to improve cereal crops in northcentral Oregon began during 1910, the first year of the Sherman Station. Emphasis was given to breeding and selecting crops and varieties to improve productivity, and to improving agronomic practices that would allow the best varieties to exhibit their greatest potential for high productivity. Production practices are summarized in other chapters.

The Scientists

Cereal breeding research specifically aimed at the needs of the dryland region of eastern Oregon has been provided by scientists located at Moro (8 breeders; 1916-1944), Pendleton (6 breeders; 1931-1994), Pullman (2 breeders; 1944-1951 and 1996-2006), and Corvallis (4 breeders; 1964-present). Their names and affiliations are shown in Appendix 2. During the 90 years in which cereal breeders had 'home' locations at Moro or Pendleton, from 1916 to 2006, cereal breeders were USDA employees during 45 of those years and OAES employees during the other 45 years. USDA scientists conducted the breeding work at Moro from 1916 to 1944, and jointly at Moro and Pendleton from 1931 to 1951, and again from 1996 to 2006.

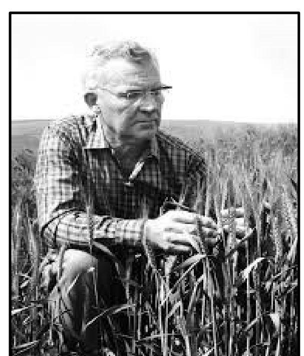

Burton B. Bayles

The Sherman Station became the home location for the first cereal breeder in the Pacific Northwest to be located at an off-campus facility. In 1916, Mr. F. J. Schneiderhan was sent from the Office of Cereal Investigations in Washington, D.C. to conduct special cereal breeding and wheat classification work at the Sherman Station. Schneiderhan assumed responsibility for cereal breeding and nursery work at the Station for a period of two years.

Mr. Burton B. Bayles was the third cereal breeder but the first of the long-serving breeders at that station. He conducted the breeding program for three years (1923-1926) before being transferred to the USDA field station near Moccasin, MT. He later earned a Ph.D. degree at the University of Wisconsin and resumed employment with the USDA at Beltsville, MD. Bayles will be mentioned repeatedly in this chapter because he continued to have a strong influence on breeding programs in Oregon and Washington, including coordinating, participating in, and visiting breeding experiments at both Moro and Pendleton for 30 years after he left the region.


J. Foster Martin

In 1927, John Foster Martin succeeded Burton Bayles as the USDA cereals breeder at the Sherman Station. After serving for three years, Martin went to Kansas State Agricultural College for one year to complete a Ph.D. degree. When he returned to Oregon on June 17, 1931, Dr. Martin was stationed at the new experiment station near Pendleton, where he became the first cereal breeder at that location. Martin's breeding position was terminated in 1950 during a constriction of the federal budget. However, Martin's service at Pendleton was not continuous. He was absent during multiple one-or-more year intervals during his last decade of 'appointment' to the Pendleton Station. From 1942 until 1950, Martin was a full-time cereals breeder at the Station only during 1945. During his absences, his cereal breeding duties were overseen by Jack McDermid (1943), Dr. Orville Vogel (from Pullman; 1944, 1946, 1948-1951), and Francis McNeal (1947 and 1948). Dr. Wilson Foote, from Corvallis, also assisted Dr. Vogel during 1950 and 1951. The breeding of wheat and feed grains in eastern Oregon during the 1940s was therefore a collaborative effort among multiple researchers at Moro, Pendleton, Pullman and Corvallis. During that time, breeding efforts were terminated at Moro.

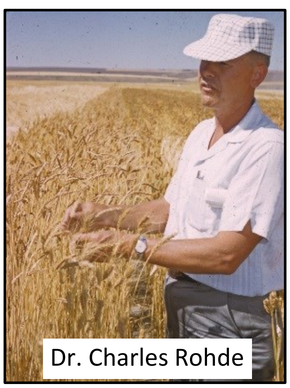

Dr. Orville Vogel

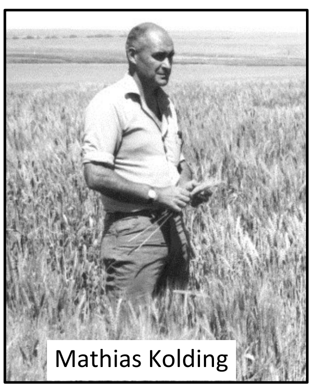
The last three USDA cereal breeders at the Sherman Station each served for one year or less; Robert Henderson (1938), Leon Hubbard (1941-1942) and O. S. Weaver (1943-1944). When Weaver departed, the USDA terminated its investment in cereal breeding at the Sherman Station. Since there was no state input into the breeding effort at Moro, there was no further breeding efforts by a resident scientist at that location after 1944.

It is of particular interest that Dr. Orville A. Vogel served intermittently for eight years (1944-1952) as USDA wheat breeder at the Pendleton and Sherman stations, in addition to his primary research responsibilities at Pullman, Washington. It was during that time, in 1949, when he made the cross that was ultimately released as ‘Gaines’, the first semi-dwarf wheat variety for the Pacific Northwest. Vogel therefore had a long and influential role in wheat breeding programs in eastern Oregon. The first documented communication between Vogel and the Pendleton Station appears to have occurred in 1931, when Dr. Burton B. Bayles, then an Associate Agronomist, Wheat Investigations, USDA-BPI, Division of Cereal Crops and Diseases, Washington, D.C., wrote to J. Foster Martin, on August 19, 1931, stating that “… *Mr. Vogel* [of the Agronomy Department at Washington State College, before he became employed by the USDA] *would like to have about one hundred and fifty grams of Fortyfold × Federation and Arcadian × Hard Federation hybrids to include in the nursery at Pullman.*” One month later, on September 15, Bayles again wrote to Martin stating “*Mr. Vogel has requested an additional 4 lbs. of Fortyfold Sel. 43*.” Thereafter, until the early 1960s, communications between Vogel and members of the staff at Pendleton were frequent. For example, on August 18, 1950, Vogel wrote a short letter to Merrill Oveson, the Superintendent at Pendleton “… *I will bring a crew of two boys to Pendleton sometime that morning. ...* [We] *want to take either Thursday or Friday off to attend the roundup. ... Chances are very good that we will have to sleep in the office because of the crowded condition at Pendleton during the roundup season. We will bring our sleeping bags with us* …”

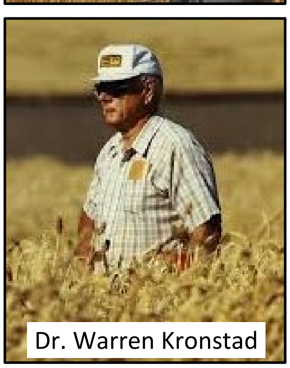
More recent cereal breeding programs at the Pendleton and Sherman stations were led by Dr. Charles Rohde (1952-1987), Mr. Mathias Kolding (1971-1985), Dr. Pamela Zwer (1988-1994), Dr. Warren Kronstad (1995-1996), and Dr. Kimberly Garland-Campbell (USDA-Pullman; 1996-2006). The focus of these breeding efforts was rather broad until the 1980s, at which time efforts at Pendleton and Moro, by Rohde, Zwer and Garland-Campbell, became focused on improvement of club wheats.

During the late 1970s, Matt Kolding summarized the organization and results of his feed grains breeding and improvement project of the Pendleton Station. In 1976, Kolding screened 5,600 early-generation populations of wheat, barley, triticale, oats and sorghum. Although most plantings were at the stations at Pendleton, Moro and Hermiston, his work also included off-station yield trials near Helix, the Rugg Farm east of the Pendleton Station, the Malheur Experiment Station at Ontario, the Kenneth Wolfe Farm at Flora, and the experiment stations at Union and Burns. Each of those locations were selected for a different level of screening for his breeding lines. Yield trials at Pendleton included wheat (732 lines), barley (465), triticale (102), sorghum (96) and oats (27). Overwinter survival and performance of winter barley (188 lines) was tested at Moro. Dwarf bunt and snow mold screening was at a high-elevation site near Flora. Early generation barley and sorghum lines were screened at Union, and winter and spring cereals were each screened near Burns. Herbicide stress tests were conducted on sandy soils at Hermiston, successfully reducing the test population of wheat lines from 1,652 down to 50 lines. His was the first breeding program designed to specifically select barley lines for production under over-head irrigation sprinklers. The Helix


Dr. Charles Rohde


Mathias Kolding


Dr. Pamela Zwer


Dr. Warren Kronstad


Dr. Kimberly Garland-Campbell


Dr. Ryan Graebner

site was used to verify the performance of wheat and barley lines selected at Moro. The Rugg Farm was used because there was too little land available at the Pendleton Station. Tests at Ontario evaluated wheat and barley lines under flood irrigation. The trial at Union was also used to screen CIMMYT's Cool-Temperature Tolerant Sorghum Nursery. The trial at Burns was to examine frost tolerance during the grain filling stages of plant growth.

Several years later, Kolding reported progress in evaluating spring and winter cereals for hay production. His tests included awnless and hooded spring barleys, spring oats, beardless wheats, and triticale. Test sites in Oregon were at Pendleton, Joseph, Union, Crane and Burns. In 1979, Kolding and Dr. Robert J. Metzger, USDA, Corvallis, reported progress in their winter triticale improvement program. They had determined that spring lines were not well adapted to the region but the productivity of winter lines was excellent. Their goal was to overcome recognized weaknesses in winter hardiness, plant height, straw strength, and seed shatter. They crossed triticale with rye to produce new lines with fewer of the poor agronomic traits. Their yield trials were conducted at Pendleton, Hermiston, and Flora.

Beginning in 1964, Dr. Warren Kronstad and his successors (Drs. James Petersen and Robert Zemetra) at Corvallis made strong contributions to all locally-important wheat classes except club wheat. Leadership for improving barley was also shifted to Corvallis, primarily in the program of Dr. Patrick Hays. The transition from breeding activities located directly in eastern Oregon to those activities being located only in Corvallis and Pullman became complete in 1994, after which time there was no longer a cereal breeder stationed at an agricultural experiment station in eastern Oregon. Therefore, this section has a focus upon wheat and barley breeding efforts in eastern Oregon between 1928 and 1994.

All current wheat breeding in Oregon is currently centralized into wheat and barley breeding programs at Corvallis. In the 1990s, the statewide cereals testing program was also consolidated into programs based at Corvallis, under initial leadership of Dr. Russell Karow and subsequent leadership by Dr. Mike Flowers. In 2018, the entire cereals testing program was moved from Corvallis to Pendleton, under leadership of Dr. Ryan Graebner. The testing program will continue to evaluate cereals in all corners of the state, including the Willamette Valley, Klamath County, Malheur County, Jefferson County, and most counties of northcentral and northeast Oregon.

Agronomists at Moro and Pendleton also made major contributions to cereal improvement programs throughout the history of those stations. Longer-serving agronomists at the stations included David Stephens, Merrill Oveson, George Mitchell, William 'Bill' Hall, Jack McDermid, Carroll Ramage, H. Marr Waddoups, F. Vance Pumphrey, Dr. Stephen Machado and Dr. Daniel Long (Appendix 2).

The Research

An introduction to the earliest wheat varieties and market classes of wheat was presented in Chapter 2. Briefly, club-type soft white wheats and hard red wheats were introduced into Sherman County during the 1800s. They included spring-type cultivars such as 'Big Club' (also called 'Crookneck Club' or 'Walla Walla Club'), 'Little Club', 'Red Fife', 'Pacific Bluestem', 'Goldcoin', 'Marquis', 'Red Russian', and 'Red Chaff' (French, 1958). Goldcoin was also planted as a winter wheat in eastern Oregon, under the name 'Fortyfold'. 'Hybrid 128' was a soft white winter wheat developed at Washington Agricultural College in 1907 from a cross between 'Jones Fife' and Little Club. While the first wheat varieties planted in Sherman County were spring wheats, it was soon discovered that varieties such as Bluestem and Fife would survive most winters and produce better crops, as well as to spread the workload more evenly across the year (French, 1958). Nevertheless, these varieties were not truly winter hardy and it was often necessary for them to be re-planted when they did not survive the winter. In 1906 the Eastern Oregon Land Company purchased six carloads of 'Turkey Red' wheat from Kansas. It quickly became the leading variety and held that status when the Sherman Station was established in 1909.

Although the first cereal breeder did not arrive at the Sherman Station until 1916, improvement of wheat varieties began in earnest during 1911, the first full year of operation at the station. That year, Harry Umberger, an agronomist and the first Superintendent at the Sherman Station, tested more than 300 varieties of spring wheat, durum wheat, winter wheat, spring barley, winter barley, spring oats, winter oats, emmer, and spring rye. He also tested varieties of flax, corn, grain sorghum, alfalfa, peas, grasses, potato, and other forage crops, which will be summarized in other chapters.

Umberger stated in the 1911 Annual Report that "*The wheat seed throughout the eastern Oregon wheat district is badly mixed, and pure seed is difficult to obtain. In 1910 the station began the work of selecting pure seed of Bluestem wheat. This seed was increased in 1911, and by 1913 a sufficient quantity* *will doubtless be on hand to begin its distribution. This practice should be followed with each of the standard varieties. Once this work is established, the influence of the station in this connection will be powerful in eliminating the constantly recurring 'new varieties' which generally prove inferior and only assist in adding to the heterogeny of varieties already grown. Unless pure seed of these varieties is distributed from the station, they are likely to disappear through the inability of the farmers to secure pure seed.*"

When Dave Stephens, another agronomist, became Superintendent during 1912 he continued the primary emphasis on wheat production but also gave much attention to barley and oats. He quickly confirmed what many farmers had already surmised and adopted; "*winter wheats were much more successful than spring varieties*." and "*There has been no attempt to do any selection or breeding work on the station with winter wheat*." As was already trending among farmers, Stephens confirmed that the Turkey Red-type winter wheats were the highest yielding and most dependable winter varieties for the region. Stephens also noted that the earlier planting dates, in late-September, produced more grain than planting dates in mid- to late-October, a fact that was unknown to farmers at that time. Stephens' observations led to a local focus on the capabilities of producing winter wheat, and also to the now common practice of planting as early as possible. Similar studies in Sherman County and elsewhere continue even today to reconfirm the observations first made at Moro in 1912. Stephens also noted in 1912 that good yields were produced by many of the spring barleys, that certain club-type spring wheats ('Little Club', or 'Washington Club') were the second-best yielders during both 1911 and 1912, and that durum wheats did not produce as well as common spring wheats. The same observations are still being made in tests conducted more than a century later.

In the 1914 Annual Report it was stated that "*The Laboratory of Plant Chemistry of the Bureau of Chemistry of the Department* [USDA] *analyzed some of the leading spring wheat varieties, and also made milling and baking tests, comparing the flour and bread from Moro spring wheats with one of the best flours milled at Minneapolis from hard spring wheat.*" This work was done during both 1913 and 1914, and photographs of the loaves that were baked with the different wheat samples were included in the report. That was the first mention of testing wheat varieties at Moro for quality characteristics. By 1915, Stephens was testing winter wheat (72 varieties), spring wheat (157), winter barley (15), spring barley (90), spring oats (42), emmer (1), spelt (1), and rye (1). During the following year, in 1916, Stephens noted that the cereal nursery work was again increased considerably over previous years, when F. J. Schneiderhan assumed responsibility for all of the cereal breeding and nursery work at the Station.

<u>Cereal Breeding and Testing at Sherman Station</u>

1. Developed and released the first pure lines of early varieties that contained mixtures of plant types
2. Determined the best planting dates for fall- and spring-sown cereals
3. Identified which market classes of wheat grew best in the region
4. Developed and released new varieties of wheat, barley and oats
5. In 1940, in eastern Oregon, 90 percent of all wheat grown was developed, introduced or bred by the Sherman Station, and improved yield by 15 percent, for an additional 1.5 million bushels
6. First cereal breeders in eastern Oregon; they were at the Station from 1912 to 1944
7. First classified wheat genotypes in the region as being of winter or spring growth habit
8. Imported seed from other countries and regions
9. Collaborated with county agents to examine yield performance in varying climates
10. First Oregon station to host the Tri-State Wheat Nursery
11. Collaborated with millers and bakers to improve milling and baking quality of wheat
12. Participated in an early national barley screening program
13. Participated in development of 'Gaines', the first semi-dwarf wheat
14. Demonstrated a remarkable yield improvement by fertilizing the semi-dwarf wheats with nitrogen
15. Demonstrated the high yields of 'Pullman Selection No. 101,' a parent of Oregon semi-dwarfs 'Hyslop', 'McDermid' & 'Stephens'

Repetitive testing at the Station led to rapid dividends for farmers in the region. The Sherman Station was able to demonstrate differences in productivity of different wheat varieties and wheat market classes. For instance, in the 1916 Annual Report, Stephens stated "*All winter wheats of the Turkey or Crimean group in the varietal test, except one, exceeded 50 bushels per acre in yield.*" It might also be noted that the exception that he referenced had a yield of 49.8 bushels/acre, which was barely below his cut-off point!

Stephens went on to state that "*The experimental work on the Substation was successful from practically every standpoint.*"

In 1917, yields of 15 winter wheat varieties that had been produced over a 4-year period were averaged by year and over the testing period. At that time, the variety Fortyfold was still one of the most prevalent varieties produced in the region. The Station's annual report showed that farmers could increase production by 13 percent, resulting in production 195,000 additional bushels in Sherman County alone, if they shifted into the production of higher-yielding varieties. "*The discontinuance of this variety* [Fortyfold] *for one of the good strains of the Turkey or Crimean group would undoubtedly greatly increase the wheat yield on the dry farms of eastern Oregon*." In response to that report, farmers started shifting away from varieties such as Fortyfold, Prohibition, and Ghirka, and began to increase their plantings of higher-yielding varieties such as Turkey Red, Argentina, Theiss and Alberta Red.

The work was again greatly amplified in field tests during 1918, even though Schneiderhan had already left after serving only one year at Moro. Each row was sown by using a small hand-pushed nursery drill. A wheat classification nursery consisting of 950 varieties was sown both in the fall and again in the spring. In the spring planting, another 128 entries were added to the collection of 950 entries evaluated in the fall planting. Notes were taken on date of first heading, date of full heading and ripeness of grain, plant height, and reaction to late season drought and heat. Entries that did not mature when planted during the spring were classified as winter wheat. Entries that died during the winter but produced grain when planted during the spring were classed as spring wheat. These findings provided much needed guidance for the farmers, who could not afford the mistakes of planting entire fields without that important information about each varieties adaptation to planting during the fall or spring. Winter wheat varieties imported from Crimea (87 lines) and spring wheat varieties imported from Australia (550 lines) or India (181 lines) were evaluated in rows that were either 33- or 50-foot long. Seventy-six barley lines were similarly evaluated. Winter wheat hybrids produced from crosses made by Schneiderhan at the Sherman Station during 1916 and 1917 were also evaluated, including head rows of many F_1 lines and of 174 F_2 lines. The goal of the F_2 crosses was to develop high-yielding beardless wheats with the Turkey-type kernel, and to also select for those lines that were winter hardy and had an earlier maturation than Turkey.

During 1919, about 75 percent of the wheat produced in Sherman, Wasco, Gilliam and Morrow counties (3.3 million bushels) was from the line of Turkey wheat selected and initially multiplied at the Sherman Station. Additional tests at Moro during 1919 also showed that several additional selections produced 13 percent more grain than the Turkey line (from Kansas) that had already been adopted for production by growers. Also during 1919, additional efforts were made to satisfy the special request from growers that the Station develop "*a non-shattering winter-hardy wheat of the Fortyfold type*." Much progress was made in identifying varieties that shattered excessively, were winter hardy, and had early maturity. That work was coordinated by J. A. Clark, another USDA cereal breeder that spent only one year at the Sherman Station.

A key finding during the early years was that the group of Federation spring wheats (Federation, White Federation, Hard Federation) were high yielding, early maturing, non-shattering, stiff strawed, and of high milling and baking qualities. Each of these characteristics were necessary for the competitive production and marketing of wheat in the Columbia Basin region. Milling and baking tests were done both at the College campus and at the Portland Flouring Mill. Hard Federation was particularly targeted for increase and distribution to farmers as quickly as possible because it exceeded the yield of the more common Pacific Bluestem variety by 36 percent. Dave Stephens reported that they had already crossed Hard Federation with winter wheats to develop a winter-hardy variety of the Hard Federation type. Grain yields in these replicated tests were subjected to statistical analysis, and the standard error of the mean was reported to show which lines were more consistent in their yields across replicates, and which lines varied greatly across replications.

In 1921, a variety trial was conducted by Sherman County extension agent C.A. Calkins, with cooperation of five farmers in southern Sherman County, to evaluate the farmer's claim that the Turkey variety of winter wheat did not yield as well as the Fortyfold variety in the shallower soils of that area. The farms were widely separated across the south county, and about one acre of each farm was devoted to these studies. Of the varieties tested in these replicated trials, the variety Triplet gave the overall best yield (29.4 bushels/acre), closely followed by Fortyfold (27.9 bushels/acre) and Turkey (27.1 bushels/acre), thereby providing experimental data that supported observations of farmers in that area.

In 1923, Burton Bayles, the third USDA cereal breeder to be located at Moro, planted as F_6-generation seed of the most promising lines from crosses made by Schneiderhan during 1916-1917. By the time Bayles arrived at Moro, most of the Australian and Indian wheat entries grown during previous years were determined to be of low promise for use in commerce or breeding and were being dropped out of the improvement program. A comprehensive effort was initiated to further improve the Hard Federation variety. Sixty-seven lines that had been selected from head rows during previous years were planted into individual plots. Much agronomic data was reported for those selections. Similar field evaluations were performed for two years with four to five selections from each of the many dozens of crosses that were made during the previous decade. Large numbers of milling and baking tests were also conducted.

Dave Stephens and Fred Bennion showing wheat, barley and oat varieties in a nursery on the McCormack Farm northeast of Pendleton during 1925, three years before the branch experiment station was established near that location; members of the tour were from the Pendleton Rotary Club

The Office of Cereal Investigations also sent 86 newly imported foreign wheat varieties and 724 barley varieties that were planted into 20-foot rows for initial screening. Bayles collected and reported a huge amount of agronomic data for each of those wheat and barley entries. Likewise, many crosses of oat varieties made during earlier years were also tested and comprehensive data was reported for a large number of agronomic traits.

Beginning in 1923, the Sherman Station's cereal breeder (Burton Bayles) and agronomists (Dave Stephens and George Mitchell), in cooperation with county extension agents, conducted dryland cereal variety tests at six off-station locations in four counties of eastern Oregon. The nurseries in each county were planted into commercial fields in collaboration with the growers and the county agricultural extension agents. That work was done with the assistance of county agents in Umatilla, Morrow and Wasco counties. During 1925 there were eight off-station cereal nurseries located near Pendleton (Umatilla County), Lexington and Eightmile (Morrow Co.), Condon (Gilliam Co.), Kent (Sherman Co.), Prineville (Crook Co.), and Dufur and Friend (Wasco Co.). Tests near

Madras (Jefferson Co.) were added several years later. In Umatilla County, an important collaborator and sponsor of the field nurseries was the Administrator of the Bureau of Indian Affairs, at the Umatilla Indian Reservation. Much of that early off-station research was focused on selecting wheat varieties that were resistant to common bunt. It is important to remember that those early tests were coordinated by the Sherman Station, well before the Pendleton Station was established in 1928. The importance of those regional tests became immediately apparent. Varietal yields and reaction to local smut strains varied among locations, as did the intensity of smut and occurrences of winter-kill. Repeated testing on the same farms provided year-to-year information on the stability of varieties at the different locations. Tests at most locations were conducted at the same farms until 1943, at which time the Sherman Station Annual Report stated that off-station nurseries in Gilliam, Sherman, Wasco and Jefferson counties were all discontinued because of the labor shortage and curtailment of travel during World War II.

John Foster Martin's cereal breeding report for the 1931 crop year at the Pendleton Station was very comprehensive (102 pages of data) and provides an excellent insight into the intensity of cereal breeding and testing activities during the earliest year of the Pendleton Station, and of test nurseries in the region before the station was established. Martin stated that George Mitchell and Robert Webb were in charge of planting his winter cereal nurseries during the previous fall, and of managing the trials until Martin arrived.

County agents assisted with trials at off-station locations. The report summarized trials with winter wheat, spring wheat, winter barley, spring barley and spring oats. For winter wheat, the report included sections to describe variety screening experiments, milling and baking tests conducted during 1930, date of seeding tests, rate of seeding tests, trials to screen wheat against multiple strains of the common bunt pathogen, trials to screen seed treatments for bunt control, and off-station trials in Umatilla County (at Holdman and Pilot Rock) and in Morrow County (at Eightmile and Lexington).

Martin reported the annual and average yields and test weights for 42 winter wheat varieties grown in replicated nurseries near Pendleton, Lexington and Eightmile since 1924. Nineteen of the entries were tested at least seven years. Three-year yield averages were reported for five varieties grown on the station since 1929; Federation, Jenkin, Hybrid 128, Albit, and Fortyfold × Federation. In 1931, they were focusing on 16 winter wheat varieties because the leading commercial varieties at that time, Federation and Hybrid 128, had scored low in nearly all milling and baking characteristics except for a high flour yield.

The level of detail in the reporting was highly detailed. For instance, in the 1931 Annual Report, Martin stated "*The 'hard pan spots' ruined the replication of the winter wheat nurseries on the station. It was a drier-than-normal late spring and a hot, dry summer, causing varieties to ripen prematurely*." This was the first of many reports of localized small patches of impervious soil layers on the Pendleton Station (see Chapter 16). Martin also stated that the nursery area near Pilot Rock was "*riddled with hard pan spots*."

They also planted the variety Federation at 2-week intervals on 15 dates from September 1, 1930 until April 14, 1931. They planted a range of seeding rates (30 to 120 pound/acre) on each date. They determined that, for the 1931 crop year, the best yields were produced when seed was planted at the rate of 60 pound/acre between October 15 and November 1. They also determined that fungicide seed treatments to control common bunt improved grain yields by 5 to 12 bushels/acre and greatly reduced the amount of smut (from up to 54 percent smutted heads in the check treatment to none in the best fungicide treatment). However, they also considered the best smut control method to be impractical; it completely eliminated the smut but entailed treating grain in a formaldehyde bath, drying it, and then coating the seed with copper carbonate.

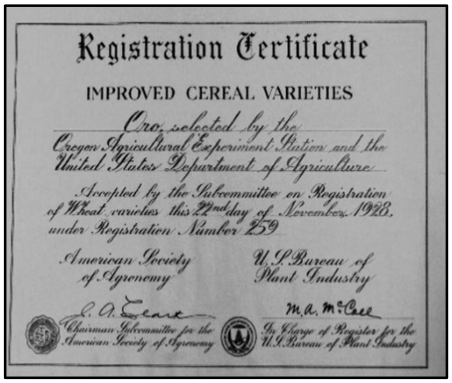
A huge nursery screened 25 wheat varieties against inoculations of each of 12 smut strains collected near Pendleton, Pullman, Heppner, Ione, Corvallis, Craigmont (Idaho), and in Indiana. The scientists counted the number of total heads per unit area and the number of smutted heads in that same area. This was a follow up to David Stephens' suspicion that there must be differences in smut strains or varieties, based on his observations in trials at Moro during 1927. The data were to be used to assess the hypothesis that there would be differences in varietal reactions based upon the pathogen strain used as inoculum. They were correct. They also tested populations of F_3 and F_4 crosses made with the intent to develop lines with resistance to common bunt. Unfortunately, none of the hybrids were resistant in that test. Much of the early wheat breeding efforts at both Moro and Pendleton were focused on finding an economical way to control common bunt. Some of those efforts are discussed in Chapter 20.

Another replicated date-of-seeding trial was conducted with 13 varieties that had either a winter- or a spring-growth habit. This experiment was prepared by Dr. Burton B. Bayles, who by that time was leading USDA wheat breeding efforts in Washington, D.C. Plantings were made from October 20 until March 14. Martin determined that, during the 1931 crop year, the winter wheats produced best with the December 5 planting date and spring wheats produced best with the February 14 planting date.

Milling and baking tests for spring wheat nurseries during 1930 were conducted at a lab in Washington, D.C., and the data were presented in Martin's 1931 Annual Report. A current-year nursery with 75 spring wheat entries was also conducted and the yield and agronomic data were presented. Annual and average data for 14 spring wheat entries tested in Umatilla County since 1923 (except 1927) were reported; seven of the entries were tested during each of those eight years.

Winter and spring barley tests were also reported by Martin. One table reported annual and average yields for four spring barley varieties that had been planted annually since 1923, except during 1927. The current replicated test, in 1931, contained 58 entries of spring barley. A non-replicated test examined another 188 spring barley selections. Spring oat (87 entries) were also screened during 1931. Three of the varieties had been tested since 1924 (except 1927) and the annual and average yields were presented in a separate table.

In 1934, Martin greatly expanded the nurseries aimed at controlling common bunt. He screened most of the wheat varieties grown in the U.S. for resistance to two different strains of common bunt. He also tested large numbers of F_2 and F_3 lines from crosses that had been made. In a nursery in which he screened 270 wheat entries against two composite collections of smut spores (one local and one PNW-regional), a great many of the entries had 80 to 98 percent bunted heads. There were only nine exceptions to the entries that showed a highly susceptible reaction; Ridit (4 and 14 percent against the local and regional smut collections, respectively), Minturki (2 and 61 percent), Oro (1 percent and trace), Ioturk (8 and 95 percent), Ashkof (5 and 7 percent), Yogo (5 and 3 percent), Meister triticale (1 and 2 percent, Hohenheimar (4 and 1 percent), Hussar × Hohenheimer (trace and trace). The local collection of smut isolates were all *Tilletia tritici*. The regional collection contained mostly *T. tritici* plus a few isolates of *T. levis*. This screening showed the immense value of including both a large diversity of germplasm and a diversity of smut isolates in tests of this type.


Registration Certificate

IMPROVED CEREAL VARIETIES

Oro, selected by the Oregon Agricultural Experiment Station and the United States Department of Agriculture

Accepted by the Subcommittee on Registration of Wheat varieties this 22nd day of November, 1928, under Registration Number 259

American Society of Agronomy

U.S. Bureau of Plant Industry

M. A. McCall

Chairman Subcommittee for the American Society of Agronomy

In Charge of Register for the U.S. Bureau of Plant Industry

Registration certificate for 'Oro' wheat

Martin further expanded the smut testing work during 1935. He repeated many of the earlier tests, and collected smut-free heads from crosses in the F_5 generation. He tested 58 different smut collections from various locations in eastern Oregon against eight different host varieties to determine the distribution of physiologic races of the smut pathogens in the region. The data allowed them to divide the 58 isolates into 12 different reaction types (races). They also tested 80 wheat varieties from India, France, Finland, Australia, Denmark, Brazil, or unknown origins. One huge replicated nursery in which the soil was inoculated with a strain of common bunt included variables of 10 planting dates, three seed treatments plus a non-treated control, and watering half the rows versus leaving soil dry in the other rows after adding inoculum to the soil. Data was presented on dates of emergence and heading, and total and smutted heads.

The pace of research on common bunt continued to accelerate during 1936 and 1937. Martin made approximately 30,000 white-kernelled and unsmutted head selections from the F_4 or F_5 generations of a number of bulk wheat crosses. The inheritance of resistance to three physiologic races of bunt in 250 F_3 lines of the cross Rex × Oro also was studied." An experiment designed to study the factors affecting protein content and milling and baking quality of wheat varieties was conducted for the first time in 1936. Another new group of 216 foreign wheat varieties was also tested to determine their agronomic value in Umatilla County. Also, 97 lines from a cross of Baart × Hard Federation – Hussar N. 1018 were planted as space plantings for Dr. Burton Bayles. Other tests of winter wheat, spring wheat, spring barley, and spring oats were the same as in previous years.

A table was presented to demonstrate that about 12 races of common bunt were distinguishable; nine were definitely distinguished in the 1936 trial and several more isolates may have represented 10th and 11th races. Another race not included in that study was also known to be distinct. That information was determined using just eight wheat varieties in the testing matrix. In another study of inheritance of resistance to three physiologic races of bunt in 250 F_3 lines of the cross Rex × Oro, the three races differed in that one infected Rex but not Oro, another was virulent to Oro but not Rex, and both wheat varieties were essentially resistant to the third smut race.

About 40,000 head selections were also made in 1937 from a large group of bulk wheat hybrids in the F_4, F_5 and F_6 generations. All selections were made from hybrids that had been free from smut when grown from smut-inoculated seed for at least two years. A large number (1,897) of 5-foot head rows were screened for white-seeded segregates of previously collected head selections, and many more smaller trials of these types were also planted and harvested. In the variety screening trials for smut resistance, there were seven varieties that had no smut at all, in comparison to 92 percent smutted heads in the susceptible control variety Hybrid 128.

Similar tests continued during the next decade and much progress was made in overcoming the most destructive disease ever to be encountered by the wheat industry in the Pacific Northwest. The immensity and importance of new knowledge that was generated from those fundamental and applied tests at Pendleton and Moro cannot be overstated.

During 1939, more than 6,500 head rows of winter and spring wheat selections were grown at Pendleton. Some of them showed definite promise as commercial varieties. The most promising were selections from a cross of Rex × Alicel, which combine early maturity, short, stiff straw, resistance to shattering, high yields, smut resistance, and satisfactory milling and baking quality for pastry products. Three new wheat varieties were released in 1939, including Athena (cross of Fortyfold and Federation in 1931), Alicel (formerly known as Fortyfold × Hybrid 128 Selection No. 942; released for growth in Union County and renamed in 1939), and Elgin (a selection from Alicel during 1932). Alicel was being grown on 10,000 acres in Union County during 1939. Also, 288 new foreign introductions were grown in single 8-foot rows during 1939.

By 1941, Rex and Rex M-1 were the leading winter wheat varieties in the area because both were high yielding and resistant to common bunt. However, both varieties were also difficult to thresh. Most grain of those varieties was exported because very little was purchased for milling domestically. The domestic grain trade bought those varieties at a discounted price because grinding caused a 'fluffy' type of flour that clogged the bolting and reduced the flour yield. Breeding efforts were therefore focused on selecting promising lines that eliminated those detractions.

More than 1,000 F_2 plants of the cross Oro × Hussar-Hohenheimer were space planted and grown in 1941 in preparation for a study of the inheritance of bunt resistance in the F_3 and F_4 populations. Hussar-Hohenheimer was resistant to all of the known races of common smut occurring in commercial fields, but was susceptible to a cross between two races (L-8 × T-9) made by Dr. C. S. Holton, at Pullman. At Pendleton, Martin and colleagues were conducting inoculation tests with isolates of the L-8, T-1, and L-8 × T-9 races. They also selected 300 F_3 lines of an Oro × Hohenheimer cross in 1940 and from the F_4 generation grown in 1941 from space-planted seed. The seed of each selection was divided into three lots and were inoculated with race T-1, L-8 or T-10. The 900 plant rows each contained about 25-40 plants. Checks in the trial included 78 rows of either Oro or Hohenheimer. Data were collected and the inheritance was analyzed. At the same time, they also screened bulk populations from about six more wheat populations (F_4 to F_7) in smut-inoculated trials.

The testing of region-wide bunt collections made in 1939 against 10 wheat indicator varieties was repeated in the trial during 1940. This trial was to determine if the planting of resistant varieties, mostly Rex, since 1934, had altered the race distribution of common bunt over the five years from 1934 to 1939. In every case, two or more races were found at every collection site. A table of comparisons of smut races found in each county, during 1934 and in 1939, was reported. Some shifts in races over time were apparent, as a result of planting resistant varieties.

Mixtures of varieties were a topic of interest from 1940 to the present time. The intent is to reduce the risk of crop failure due to situations such as winterkill or severe damaged by foliar diseases such as stripe rust or barley yellow dwarf. If a mixture of cold-sensitive and cold-insensitive varieties are planted, only a portion of the plants will be affected during particularly cold events that occur without the protection from snow cover. Likewise, if a foliar disease occurs, a mixture of varieties that differ in susceptibility can reduce the risk of total crop failure if the weather becomes particularly favorable for development of that disease. The first variety mixtures tested in eastern Oregon were at the Sherman Station from 1940 until 1944. They planted a mixture of four varieties and compared the mixture with each variety planted separately. While the five-year mean grain yield for the composite was slightly greater than that for each of the four components, the five-year mean test weight was slightly less than that for each of the four components. Under the conditions of those tests, the scientists concluded that there was not likely to be a benefit from planting mixtures rather than planting individual varieties. Nevertheless, as a risk-management strategy, the planting of varietal mixtures continues to be a point of interest for agronomic research in eastern Oregon seven decades later. The planting of mixtures would become restrictive if the commodity market develops an incentive to segregate varieties for a purpose such as selling varieties with the highest possible quality at a premium price.

The first year of planting the Tri-State Wheat Nursery at the dryland research stations occurred during 1948, at a time when leadership for the breeding program for eastern Oregon was being provided by Dr. Orville Vogel, USDA at Pullman. This cooperative regional test was established "*… to see and test each others best soft white wheat selections*."

The Sherman Station 1948 Annual Report summarized investigations with winter and spring barleys, oats and wheats at Moro and seven off-station nurseries in Gilliam (Condon and Shuttler Flat), Morrow (Ione and Eightmile), Wasco (The Dalles) and Wheeler (Spray and Richmond) counties. Off-station nurseries in Sherman County, as well as in the previously mentioned counties, were summarized again in the 1950 and 1952 Reports. The 1950 Report also stated that "*... grain bundles from extension service fertilizer demonstration plots were threshed, cleaned and weighed at this* [Sherman] *station*."

Another leap forward was shown in the 1948 Annual Report. This was the first time that the report included a section entitled Wheat Quality Investigations. Milling and baking data had been included in the station reports from 1918 to 1929 but then were not reported again until 1948. It was also stated that "*In the breeding program, little attention was paid to quality, with the exception of test weight and possibly protein content, prior to the release of the variety, Rex. This variety is agronomically good but has poor milling quality. It became grown on such a large acreage that millers could not blend it with other wheat and began to complain about its milling quality. This led to a re-emphasis on quality in the breeding program and started a cooperative movement between wheat breeders and millers in the Northwest to produce better quality wheat varieties. In 1948, a milling trial was made on an Alicel × Rex selection which appeared very promising agronomically. It proved unsatisfactory in the mill, acting much the same as Rex and has been withdrawn from release. The tests were run at three laboratories: (1) USDA Milling and Baking Laboratory by Dr. Fifield; (2) Colorado Milling and Baking Laboratory by Mr. Arthur W. Gust; and (3) by J.W. Montzheimer of Centennial Flouring Mills for the Northwest Millers Association. Comparison of varieties should be made within the same tests as laboratory techniques differ with the various millers.*"

By 1950, most barley land in the Columbia Basin had been replaced by wheat. Barley had become a crop grown mostly for feed or hay on the farm, and little grain was being sold. Only two barley varieties were being produced. This situation emphasized a need for better barley varieties in the region. The main objectives of the breeding program had been aimed at increasing the yield, improving straw strength, improving resistance to shatter, and developing a winter-hardy variety that had smooth awns or hooded heads. Much agronomic data was presented for barley trials in 1950. Winterkill provided a strong segregation of the hardiness trait; only a few of the 1949 crosses and none of the 1950 crosses survived. Good data was obtained for all experiments with spring barley at Moro and each of the off-station locations. The Sherman Station also participated in a nation-wide comparison of 2-row and 6-row barleys. Results were variable depending on the location of the field trial.

The acreage of oats in the Columbia Basin had also become quite small by 1950. Under dryland conditions, oats had been found to be the most variable in yield of any of the cereals. Oats were grown only for hay, and were mostly being planted in strips around wheat fields. The oat hay could be cut so that the first round of the then-current combines, with side-mounted headers, wouldn't destroy the grain that would occur if wheat had been planted along the borders of fields. A winter-hardy oat was preferred but there were none available at that time. For instance, there were no survivors in the winter oat nursery again during 1950. The decision was made to curtail breeding work with oats and to continue with only small test plantings of winter varieties to test for winter hardiness.

Testing during the 1940s was reduced during the frequent absences of Martin and the shifting of cereal breeders that carried the work forward. That instability ended when Dr. Charles Rohde became the wheat breeder for the Pendleton and Sherman stations in 1952. He quickly amplified the number of off-station trials to include locations in each of the eight wheat-producing counties of northeast and northcentral Oregon. Rohde's work in eastern Oregon became supplemented when Warren Kronstad moved from Washington State University in 1959 to become an Instructor in the Farm Crops Department at Oregon State University. Kronstad conducted some of his doctoral dissertation research at the dryland stations in eastern Oregon. Kronstad's contributions became accelerated after he received the Ph.D. degree in 1963 and was promoted to a professorial position at Oregon State University.

During Rohde's first few years at Pendleton, most breeding work on winter wheat continued with an emphasis on varieties with resistance to common bunt and dwarf bunt. During 1952, Rohde conducted an inheritance study of resistance to races T1, T14, and T16 in the 1,471 F_3 lines of three crosses based on Elgin and Elmar as parents. He collected 1,338 smut-free heads from those entries and inoculated the seed with race T15 and planted it for evaluation during the 1953 crop year.

In 1952, a new program was established to screen all of the USDA Cereal Investigations (C.I.) Collection of Wheat Varieties for smut resistance at the Pendleton Station. The program was a collaboration by Drs. Charles Rohde, Burton Bayles (Washington, D.C.), C. Stewart Holton (Pullman, WA), Orville Vogel (Pullman, WA), and Wilson Foote (Corvallis). Vogel had served as the wheat breeder at Pendleton until 1951, at which time Rohde was appointed to that position. Bayles supplied the seed for 4,700 entries during the first year and Holton divided each seed lot and inoculated half of the entries with race T1 and the other half with T15. In 1952, Vogel and Foote assisted Rohde with the planting and note taking. That team also planted another 3,700 lines of the C.I. at the Sherman Station. Vogel presented a synopsis of that research at the Annual Meeting of the Oregon Wheat Growers League in 1952 (Vogel, 1952). His 10-page written statement included the following. "*Recently, as new more virulent races of smut begin to appear it became apparent that we soon might run out of factors for smut resistance. Consequently, in 1950 the smut inheritance studies were reactivated at Pendleton with the aid of funds from the Oregon Wheat Commission and at Pullman with funds from Washington State College.*" Later in his speech, he stated "*A new field of genetic study was undertaken in 1950 by Bill Hall, stationed at Moro. He made the first attempt to study the inheritance of milling quality in wheat. … He did a remarkably good job of opening up the new field of study*." Vogel went on to state that the Pacific Division of the Association of Operative Millers contributed funds to defray some of Hall's expenses while he worked at the Regional Quality Laboratory at Pullman.

Collections of wheat were sent for planting during the fall of 1952 and examined for resistance to races T1 and T15 during the 1953 crop year. Poor emergence of that nursery made the test unreliable, causing them to repeat that test during 1954. By 1955, about 10,713 varieties from the world collection had been tested for resistance to races T1 and T15 common smut. The 3,037 entries that appeared to be resistant were then screened for their reaction to races T2, L2 and T14. The 370 entries that appeared resistant were then screened for reaction to T10, T13 and L8. That line of research continued for many years. By 1957, after five years of testing, they had screened the 1952 group of entries against 15 races of the pathogen. Only 43 varieties from that original group had shown a fairly high degree of resistance to most smut races. Three selections, two of which were Einkorn wheat, were resistant to all races to which they were tested. The 1953 group had been tested against 13 races and 70 varieties showed a useful level of resistance, with 21 lines being resistant to all 13 races. The 1954 group had been tested against eight races, and 26 of that group showed high resistance, with nine of them being resistant to all eight races of the pathogen.

During 1954 growers had expressed an interest in determining whether they could shift to the production of a hard red wheat due to the surplus of soft white wheat. But they needed to know if they could satisfy the minimum protein requirement for hard red wheat. Fertilizer trials were conducted in 1954 with rates of applied nitrogen up to 120 pound N/acre. The protein increased up to 12.2 percent with increasing rates of nitrogen up to 80 pound N/acre, but then didn't increase further with higher rates of nitrogen. Higher rates of nitrogen reduced the test weight and market grade of wheat produced. It was determined that it would not be economical to apply fertilizer in an attempt to produce high-protein bread wheat under dryland conditions in the areas tested.

The growers then turned their interests to the possibility of producing durum wheat, due to newspaper stories about the loss of the durum crop in the mid-west from a rust epidemic. Durum had been grown during the early years of the Station and had been found to be unprofitable. A small nursery of new durum varieties was grown in 1955. As had been shown during the 1920s, durum yields were again considerably lower than the yields in the on-going wheat variety trials. Additionally, the protein level in the durum was too low for use in commercial production.

During the first 50 years of the Sherman Station, the staff at that location were key developers of three barley, two oat, and 15 wheat varieties (see sidebar). Although Leon B. Hubbard, at the Sherman Station in 1942, made two crosses that led to release of the varieties Columbia and Itana, each of those varieties was released by another state. Merrill Oveson made repeated reselections from those crosses at Moro during the 1940s and, in 1951, placed the best-producing line from each cross into the Western Uniform Hard Red Winter Wheat Nursery. Both lines performed very well in very low rainfall areas and they were resistant to common bunt. In 1954, Bill Hall made further selections to produce bulk seed lots at Moro. Similar work was done at Lind, Washington. Washington State University registered Columbia as a variety in 1955. Itana was registered by Montana State University in 1956 and by the University of Idaho in 1957. Itana became an important commercial variety in Idaho, Montana and Washington but not in Oregon. In addition, selections from the 1919 crossing of Fortyfold and Hybrid 128 became part of the breeding material that led to development of the Washington varieties Elmar (1949) and Omar (1955).

Cereals Released by the Sherman Station

Barley:
1. Meloy (1916)
2. Flynn (1941)
3. Spray (1949)

Oat:
1. Marketon (1924)
2. Carleton (1938)

Wheat:
1. Federation (1920)
2. Turkey (1926)
3. Oro (1927)
4. Hard Federation (1928)
5. Sherman (1928)
6. Arco (1928)
7. Hard Federation 31 (1928)
8. Golden (1930)
9. Rio (1931)
10. Athena (1931)
11. Alicel (1932)
12. Rex (1933)
13. Elgin (1943)
14. Columbia (1955)
15. Itana (1956)

Small grain breeding programs in eastern Oregon became further amplified when, in 1969, the Oregon Wheat Growers League requested that a feed grains research program be initiated at the Pendleton Station. An initiative to fund that initiative was passed by the State Legislature that same year. Mathias Kolding was hired as the feed grains breeder at the Pendleton Station in 1971. Kolding's program focused mostly on improving crops of barley and triticale, including research on cereals produced for hay crops. Kolding also collaborated with colleagues at Corvallis who were attempting to develop malting barleys adapted to the dryland region. Kolding transferred to the Hermiston Agricultural Research and Extension Center in 1985. The following year, Dr. Patrick Hays became Oregon's barley breeder and geneticist, located at Corvallis.

Dr. Charles Rohde retired in 1987 and was succeeded by Dr. Pamela Zwer. Her program emphasized the development of wheat varieties in the club wheat market class. Zwer was denied tenure in 1994, at which time she immediately accepted responsibility for leading a much larger and well-funded breeding program in Australia. Since that time, there have been no on-site small grain breeders working at either of the dryland research centers in eastern Oregon. After Zwer's departure, the club wheat breeding work in which she had been engaged was temporarily overseen by Dr. Warren Kronstad and was then continued for another decade as a component of Dr. Kimberly Garland-Campbell's USDA-ARS breeding program at Pullman. Campbell supplied a research assistant, equipment and operating funds to continue with breeding trials at Pendleton and Moro. Federal funding for that collaboration was terminated during 2006. During the past decade the wheat breeding in the region became centralized into the cereal breeding programs at Corvallis. Dr. Jim Peterson succeeded Dr. Warren Kronstad as Oregon's wheat breeder, and Peterson was succeeded by Dr. Robert Zemetra.

Cereals Released by the Pendleton Station

Barley:
1. Ione (1967)
2. Mal (1980)
3. Hesk (1980)

Wheat:
1. Moro (1965)
2. Adams (1968)
3. Rew (1974)
4. Faro (1976)
5. Oveson (1986)
6. Rohde (1993)
7. Temple (1996)

In 1964, when there was no longer a cereal breeder at the Sherman Station, the cereals program at Moro became totally focused on agronomic production practices. The initial emphasis was on fertilizer experiments both on- and off-station to optimize conditions for producing the best yields of Gaines winter wheat. This was followed by similar studies on Nugaines and Moro, which became the leading two varieties grown in the lower rainfall areas by 1970. The importance of the stations at Moro and Pendleton in the development of these and other varieties is discussed later.

During the 1960s and 1970s, Dr. Warren Kronstad (Corvallis), Dr. Charles Rohde (Pendleton) and Mathias Kolding (Pendleton) continued to test winter and spring cereals at Moro. Kolding's program emphasized triticale and Kronstad and Rohde's programs emphasized wheat. Irrigated winter wheat and winter barley nurseries were also conducted on the Sherman Station during 1971. An unforeseen mid-summer water restriction, required by the City of Moro, came at a critical time in the development of these crops, causing lower than expected yields and a failure of the irrigated nurseries during 1971. By the 1980s the Corvallis-based breeding program screened its wheat nurseries on fields managed as a three-year rotation involving one year in winter wheat and two years in fallow. Yields from those trials were substantially higher than yields attained by the growers, all of whom were using a two-year wheat-fallow rotation. By the late 1990s, most of the Corvallis-based wheat improvement program had been moved off the Sherman and Pendleton Stations and onto farms that could supply pre-plant irrigation to assure efficient seedling establishment even during years with marginal conditions for seedling establishment. Yields from those trials were often also higher than yields attained by growers in each region.

Extensive production technology was also developed for cereals throughout the histories of the stations at Moro and Pendleton. Agronomic studies on wheat planting date, planting depth and seeding rate, fertilizer timing and rate, and others such topics are summarized in other chapters.

Examples of Wheat Varieties Directly Linked to Research at Moro and Pendleton

The first wheat varieties released from the Sherman Station were pure lines developed by picking individual heads from stands of existing varieties that exhibited considerable variation among plants. For instance, the re-release of Federation in Oregon, in 1920, was derived as a pure-line selection from the Federation released in Australia in 1914. This was a common practice at that time, and several other states re-released their own selections from the original Federation. Turkey and Oro were pure-line selections from Turkey No. 889, and were developed by D. E. Stephens and H. M. Woolman. The Sherman Station also released Hard Federation 31 in 1928; it was a pure-line selected by B. B. Bayles and D. E. Stephens from Hard Federation, which had been developed and released in Australia in 1915. The first hybrid wheat released as a variety from the Sherman Station was the variety Sherman. It had the pedigree of 'Budapest/Turkey//Zimmerman/Turkey', and was developed by J. A. Clark and M. A. Carleton. Those scientists also released the variety Arco, which had the pedigree of 'Arcadian/Hard Federation'.

Another very successful release from the Sherman Station was 'Golden'. It was released by D. E. Stephens in 1930 as a pure-line selection ('Goldcoin Selection No. 43') from Fortyfold, which was Oregon's winter wheat version of Goldcoin, which had been released in New York in 1890. Other varieties released from the Sherman Station by D. E. Stephens included Athena ('Goldcoin/Federation'), Rio (pure-line from 'Argentine CI 1569'), and Alicel ('Hybrid 128/Fortyfold'). Alicel was produced on 233,803 acres in 1949.

Dave Stephens and Dr. J. Foster Martin released the variety Rex in 1933. It was a hybrid selection from the crossing of White Odessa and Hard Federation. It became a widely produced soft white winter wheat that was produced on 449,787 acres in 1944. Production of Rex declined to 154,878 acres in 1954 and it was no longer being planted by 1974. It was high yielding, early maturing, resistant to lodging and shattering, and moderately resistant to most races of common bunt. A pure-line reselection, Rex M2, was re-released by Washington State College in 1938.

Stephens then released the variety Elgin in 1943, a club wheat that was a pure-line selection from Alicel. Elgin was produced on 596,293 acres in 1949 and continued to be produced on smaller acreages until 1980. In 1955, C. R. Rohde released the variety Columbia from the Sherman Station; its pedigree was 'Rio/Rex//Nebred'. Rohde also developed the germplasm ('Blackhull/Rex//Cheyenne') that was released by Montana State University as the variety Itana, in 1956.

The most successful of the varieties released by the dryland experiment stations in eastern Oregon became key stepping stones for crosses that became even more successful and more widely planted in Washington. As examples, the Oregon club wheat variety Elgin was replaced by the release in 1949 of the variety Elmar. It was released in Washington and had a pedigree ('Hymar/3*Elgin') designed to incorporate the smut resistance of Hymar into an Elgin-type plant. Elmar was planted on nearly 1.5 million acres in 1954. It was replaced by the release in 1955 of Omar, another club wheat from Washington. Production of Omar exceeded 1.5 million acres in 1959. Omar's pedigree was also considerably influenced by two varieties (Oro and Elgin) developed at the Sherman Station; 'Oro/2/Turkey Red/Florence/3/3*Elgin, Elgin Sel. 19)/4/Elmar'.

During the 1940s and lasting until the 1990s, it became nearly impossible to distinguish research activities at Moro and Pendleton. That research was also inseparably linked to research at Pullman and/or Corvallis. This linkage is exemplified by the development and release of important varieties such as Gaines, Moro and Stephens. The first such example represents research that was coordinated from Pullman but included important work at both Moro and Pendleton. The research in Oregon was led by Dr. Charles Rohde who, collaborated closely with five cereal breeders and several smut pathologists based in Pullman, Washington; particularly Drs. Orville Vogel, Robert Allan, Clarence 'Pete' Peterson, Calvin Konzak, Robert Nilan, and C. Stewart Holton. It was through that collaboration that 'Gaines' was developed and became the first agronomically acceptable variety of semi-dwarf wheat. Development of 'Stephens' also demonstrated the close linkages between several breeding programs in eastern Oregon and those at Pullman and Corvallis. The focus of wheat breeders at Pendleton for developing club-type wheats such as 'Moro', 'Rohde', and 'Temple' also featured multi-locational collaborations.

Omar foundation seed produced at the Pendleton Station

'Gaines' (1961)

Development and release of the Northwest's first semi-dwarf variety by Washington State University in 1961 was a part of the 'Green Revolution' (Scheuerman and McGregor, 2013). Development of Gaines had a direct link to breeding programs at both Moro and Pendleton.

Dr. Burton Bayles, formerly at the Sherman Station, continued to send rather large wheat nurseries for testing at Pendleton and Moro at least until the early 1950s. During 1949, he sent a collection of Japanese semi-dwarf wheats to all USDA wheat breeders in the United States, including Dr. Vogel at Washington State College in Pullman. At that time, Vogel also served as the wheat breeder for the Pendleton Station. Vogel continued to have a strong influence at Pendleton until the early 1960s. He recognized that smut-resistant winter wheat varieties such as 'Omar' and 'Brevor' were highly resistant to lodging when they were released, but were prone to extensive lodging when growers planted them earlier in the fall and applied higher rates of nitrogen fertilizer.

Vogel crossed a Japanese semi-dwarf selection named 'Norin 10' with Brevor during 1949. Brevor had recently been determined to be resistant to common bunt throughout the region and to dwarf bunt in Oregon. The best segregates from that cross were not considered suitable for release because Norin 10 also contributed inferior traits such as partially male-sterility, high susceptibility to most wheat diseases in the region, and a brittle rachis that caused many heads to snap off before being harvested. Segregates that included Norin 10 parentage therefore had to be crossed with additional varieties and hybrids to remove the unacceptable traits. Most segregates from the additional crosses were also of little commercial value. However, one line that was designated as 'Norin 10 × Brevor, Selection 14' became famous internationally as the parent that contributed a strong increase in grain yield as well as a short stature that was resistant to lodging. Selection 14 and others were sent to Dr. Norman Borlaug at the International Maize and Wheat Improvement Center (CIMMYT). Borlaug crossed Vogel's semi-dwarf selections with Mexican wheat varieties to create the varieties Sonora 64 and Lerma Rojo 64, which provided the basis of the Green Revolution in India, Pakistan and other countries.

Dr. Vogel also continued to improve Selection 14. The pedigree which led to development and release the variety Gaines included Selection 14 and at least five varieties that had been released by the Sherman Station; Turkey, Oro, Federation, Rio and Rex. Gaines became the Pacific Northwest's first semi-dwarf wheat suitable for commercial production and was registered by Washington State University in 1964. Another of Vogel's highly productive Norin 10 × Brevor crosses was 'Pullman Selection No. 101', which will be discussed in the section on 'Stephens' wheat.

The first mention of Vogel's semi-dwarf winter wheat selections being tested in Oregon occurred in the 1953 Pendleton Station report prepared by Dr. Charles Rohde, and in the 1959 Sherman Station report prepared by William Hall and others. On September 8, 1952, Vogel sent Rohde and other breeders packets of seed containing 50 grams of Brevor, Norin 10, and F_5 generations of Brevor × Norin 10 Selections 1, 4 and 10. He included a table of plant heights and yields of grain and straw produced by all five cultivars during his 1952 trial at Pullman. The plant height for Brevor was 41 inches and that of Norin 10 and the three F_4 generation crosses was 25 to 28 inches. Yields of the crosses were as much as 12 bushels greater than either parent. All selections tested during 1952-1953 were among the top-ranked entries in the on-station tests during their first year of testing at both Pendleton and Moro. They produced high yields and test weights, which were well above those of Omar and Elgin, the standard varieties of that time.

Norin 10 × Brevor crosses were tested again in wheat nurseries at Pendleton during 1954 and were again the highest yielding varieties. Rohde concluded that "*These results indicate that high yielding short-strawed varieties are a definite possibility*." There were six crosses tested in 1954, including Norin 10 × Brevor-14, the cross that ultimately led to development of Gaines wheat. A massive amount of agronomic trait data were collected. The data and summary for that trial alone occupied nearly 40 pages of the 1954 cereal breeding program's annual report. Also, 1954 was the first year that a Norin 10 × Brevor 1 cross was placed into the off-station trials, located in Union County (Elgin, Alicel, North Powder), Wallowa County (Lostine, Enterprise), Baker County (Haines), and Umatilla County (Echo, Helix, Pilot Rock, Weston). The joint effort by these wheat breeders was evident in a letter from Orville Vogel to Chuck Rohde, dated March 11, 1955. That letter stated "*So far I have not had time to write our semi-dwarf paper which we want to have published in the Agronomy Journal. … I will try to have the first draft of our paper completed within the next three weeks and will send it to you for your consideration*." The letter continued by stating that Vogel had drafted an abstract of a joint presentation they would make at the American Society of Agronomy meeting in August 1955. The title was "*Semi-dwarf growth habit represents desirable progress in winter wheat improvement for the Pacific Northwest*." The abstract included five authors: Drs. O. A. Vogel, J. C. Craddock, C. E. Muir, E. H. Everson, and C. R. Rohde.

Rohde also made crosses at Pendleton during 1954 to combine the semi-dwarf trait with the desirable qualities of Oregon's best varieties. He used three semi-dwarf parents; Norin 10 × Brevor 17, Norin 10 × Brevor 14, and Norin 10 × Brevor 11. With the arrival of Donald George, they also made crosses to increase the cold hardiness of the most popular winter wheat varieties at that time. That same year there was a strong resurgence in the occurrence of common bunt in eastern Oregon. The bunt was especially bad in areas north of Helix and Athena. That occurrence led Rohde to emphasize that they needed to replace Elmar with a more smut resistant variety as soon as possible.

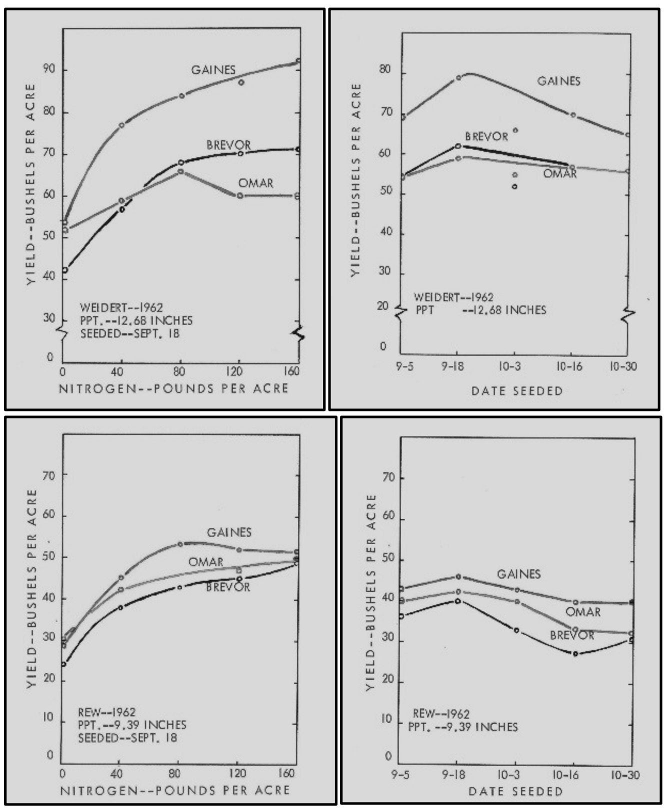
In collaboration with Rohde, Vogel continued to test his breeding lines in Oregon and, in 1957, he released two publications printed by the OAES. Those 4-page bulletins authored by Orville Vogel announced the release and attributes of two new winter wheat varieties, Burt and Omar.

None of the semi-dwarfs in the earliest tests at either location in Oregon was Selection No. 14, the 1949 cross between Norin 10 and Brevor that was ultimately improved by backcrossing to produce a line that became named Gaines. The first year of testing in Oregon of the semi-dwarf selection that became registered as Gaines occurred in 1960. That selection was entered into Dr. Rohde's trials at Pendleton as '(14 × 53) × Burt Sel. 9; C.I. 13448', and at Moro as 'Pull. 14 × 50-3 × Burt Sel. 9; C.I. 13448'. The pedigree of Gaines was very complex and included several varieties released by the Sherman Station; '(Norin 10 / Brevor, CItr13253, Sel. 14) /6/ (Sel. 3, CItr12692, Orfed /5/ (Hybrid 50, Turkey Red / Florence /2/ Fortyfold / Federation /4/ Oro /2/ Turkey Red / Florence /3/ Oro /2/ Fortyfold / Federation)) /7/ Burt'. That line produced the highest yield among 50 entries in the advanced winter wheat nursery at Pendleton and the second-highest yield in the test at Moro. The yield of C.I. 13448 was 10 or more bushels/acre greater than commonly produced varieties such as Burt, Elgin, Elmar and Brevor, and were nearly double the yield of the old standard Kharhof. C.I. 13448 also produced excellent test weights and was 20 inches shorter than Kharhof at Pendleton, and 9 inches shorter that Kharkof at Moro. That selection also performed very well in Wheeler County, but was among the lowest yielding varieties tested in Gilliam and Morrow counties. It is perhaps ironic that, at the time when Vogel's C.I. 13448 was first tested in Oregon, Rohde was moving one of his semi-dwarf lines (C.I. 13440) toward release. Rohde's line had better milling and baking traits than Vogel's line, but was a bit lower in grain yield. He therefore crossed C.I. 13440 with Selection 101(C.I. 13438), an even higher-yielding semi-dwarf.

Gaines was released as foundation seed in 1961 and was tested under that name at Pendleton and Moro that same year. Fifty-five farmers in Umatilla County planted Gaines during the fall of 1961. They were required to adhere to Oregon Seed Certification rules to produce certified seed that would be harvested in 1962. These were the first commercial growers of Gaines wheat in Oregon. They were required to sell 60 percent of their production of that new variety to other growers, after it was cleaned, treated, bagged, and tagged with Oregon certification tags. At the same time, scientists at the research center initiated multi-year experiments to refine information on regarding optimal planting dates and rates of nitrogen application.

The 10-acre studies compared Gaines, Omar and Brevor at five planting dates and six rates of nitrogen at farms in three precipitation zones; west of Pendleton (Ron Rew Farm), west of Helix (John Weidert Farm), and south of Weston (Sam Crow Farm).

Gaines soon became the dominant variety in the region and produced very high yields under dryland as well as irrigated conditions. It could be planted earlier in the fall and therefore provided better control of soil erosion, however it also led to a great increase in the amount of fertilizer applied. It also had short coleoptiles that were very slow to emerge. A deep-furrow drill was developed to overcome that limitation. Gaines became a recommended variety for all areas where the semi-dwarf characteristic was not detrimental. Results of early findings regarding the increased productivity of semi-dwarf wheats were published in scientific journals (Vogel et al., 1956; Vogel et al., 1963). One of the contributing authors of the latter paper was Dr. Charles Rohde. Gaines was registered (Vogel, 1964) and planted on more than 1.6 million acres in 1964. However, Gaines also lacked effective competitiveness with winter annual weed species, was susceptible to stripe rust, and was difficult to mill into flour. Efforts were immediately implemented to overcome those undesirable traits. A reselection from Gaines exhibited better resistance to rust and better milling traits. The reselection was released as 'NuGaines' in 1965. The first mention of NuGaines in tests at Pendleton and Moro occurred during 1966. In those trials, both Nugaines and Gaines were among the best performing varieties. Many other crosses tested were of the type "(Nrn 10 × Bvr-14) × Burt^5 #11; C.I. 13739", which were sister segregates of crosses that led to release of Gaines and Nugaines. Nugaines was planted on nearly 1.5 million acres by 1969 and was still being planted on more than 1.6 million acres in 1974.



Effects of nitrogen application and planting date and on productivity of Gaines, Brevor and Omar wheat at the Weidert (top) and Rew Farms (bottom) during 1962; data of Dr. Robert Ramig.

'*Stephens*' *(1978)*

As stated earlier, two of the highest yielding winter wheats at Pendleton included the French variety Nord Desprez and the semi-dwarf 'Pullman Selection No. 101.' Selection 101 was one of Dr. Orville Vogel's Norin 10 × Brevor crosses that was among the highest yielding lines tested at Moro as early as 1960. Moreover, yields of Nord Desprez, Selection 101, and Gaines were far more responsive than other varieties when additional fertilizer was applied to soil before the seed was planted. Application of fertilizer improved yields of those varieties by another 10 bushels per acre at both Pendleton and Moro.

During subsequent years the adaptability of the Vogel's semi-dwarfs Gaines and Pullman Selection No. 101 were repeatedly tested throughout the region to identify areas of greatest adaptability. In 1962, Selection 101 was the highest yielding variety (65 bushels/acre) at Moro. In 1963, Gaines produced the highest yield at 52.0 bushels/acre and Selection 101 (entered as Pullman 14-53) ranked second with a yield of 48.7 bushels/acre. Most other entries yielded in the range of 30 to 40 bushels/acre. In these nurseries over the four years of testing, the average yields of Gaines and Selection 101 (as Pullman 14-53) were 46.7 and 49.3 bushels/acre, respectively. In 1964, Selection 101 was the highest yielding of the 120 winter wheat entries at Moro. Selection 101 and Gaines also performed very well in outlying nurseries throughout eastern Oregon, indicating their wide adaptation.

The French varieties Nord Desprez and Cappelle Desprez first appeared in Dr. Rohde's field trials at Pendleton in 1958. Both varieties were among the highest yielding entries in all nurseries at Pendleton from 1958 to 1961. By 1959, Rohde was using Nord Desprez in a series of complex crosses to improve winter wheat. The goal was to include parents that improved agronomic adaptability to the region, resistance to common bunt, and improved straw strength, milling qualities, and winterhardiness. Rohde began annual screenings of progeny from those Nord Desprez crosses for resistance to common bunt.

At the time, Rohde was testing in the field progeny of crosses containing Nord Desprez as one of the parents, Vogel and the smut pathologists at Pullman continued to screen their varieties for resistance to large numbers of common bunt races at the Pendleton Station, in collaboration with Rohde. Warren Kronstad was a Master's Degree student and then an employee of Vogel at Washington State University until 1959, when he became an Instructor in the Farm Crops Department at Oregon State University. After receiving his Ph.D. Degree in 1963, Kronstad crossed two of the highest-yielding lines he had observed in Rohde's tests at Pendleton and Moro. He crossed Nord Desprez with Pullman Selection No. 101 during 1965 and then backcrossed that line with Selection 101 to improve its agronomic adaptability to the region.

Crosses of the semi-dwarf genotypes with Nord Desprez in both Rohde's and Kronstad's programs began to appear in field tests at Moro during 1967. Those lines included a number of crosses, several of which were of the Nord Desprez × Selection 101^2 type. The line designated as Nord Desprez × Sel. 101^2 (C.I. 63-130) first appeared in tests at Pendleton in 1967 and at Moro in 1968. For the following four years, that line was the highest yielding entry in the winter wheat trials at Pendleton. It was released as McDermid in 1976. The Sherman Station Annual Report for 1973 was dedicated to Jack T. McDermid, who served as Superintendent of Sherman Station from 1964 until his death in January 1973. It was stated in the dedication that "*The new white wheat variety* [McDermid] *(Nord Desprez × 2 Pullman Sel 101) Sel. 63-130-66-5, C.I. 14565, was named in honor of Jack.*"

The Nord Desprez × Sel. 101^2 (OR65116) cross that became named Stephens (C.I. 17569) did not appear in nurseries at Pendleton until 1973 and at Moro until 1974. In 1973 and 1974, the cross was designated as 'ND/Sel. 101, 65-116-70-MBW-2, OR711'. In 1975, that cross began to be tested at off-station locations, and it was tested under a number of different designations; 'Nord Desprez/Sel. 101; OR65116' in most trials, 'Stephens; C.I. 17569' in the advanced irrigated winter wheat nursery, 'NdD/P101, 65-116-70-MBW-2; OR7424' in the preliminary irrigated winter wheat nursery, and 'ND/Sel. 101; OR65116' in the off-station tests at Pilot Rock, Rew Farm, Holdman, Arlington, Heppner, Condon, Weston, LaGrande, and Enterprise. In 1976, Stephens continued to be tested under a number of different designations, including 'Stephens', 'Stephens (OR65116; C.I. 17569', 'Stephens; C.I. 17569', 'Nord Desprez/Sel. 101; OR65116', and 'ND/P101, 65-116-70-MBW-2; OR7424'. Those designations were among the highest yielding entries at most locations where they were tested during 1975 and 1976. During the first three years of testing at the Sherman Station, Stephens was one of the few varieties that produced yields that were at least double that of Kharkof, the then current standard for comparison.

Stephens became registered as a variety and was released for commercial production in 1978 (Kronstad et al., 1978). The following year, in 1979, Stephens was planted on nearly 700,000 acres. It was still being planted on nearly 2 million acres in 1984. It became the most successful of these semi-dwarfs because, in part, it was well adapted to a wide range of environments and exhibited excellent resistance to stripe rust. The rust resistance genes were inherited from the Nord-Desprez parent and the high-yield potential was inherited from the Selection No. 101 parent. The variety was named in honor of David Stephens, who was the former Superintendent of the dryland experiment stations, and had released many of the earlier varieties in northcentral Oregon. While Dr. Warren Kronstad was the key coordinator of the registration of Stephens wheat, the authorship for that registration included two authors from the Pendleton

Station, Dr. Charles Rohde and Mathias Kolding, both of whom were key collaborators in the development of Stephens wheat.

‘*Moro*’ *(1965)*

This club-type winter wheat was selected from a cross made in 1957 by Dr. Robert Metzger, a USDA wheat geneticist and smut pathologist at Corvallis. Metzger crossed a Turkish selection (P.I. 178383) with Omar and then backcrossed the progeny with Omar. The F_1 lines were planted at the Pendleton Station in the fall of 1957. Testing by Drs. Metzger and Rohde, at Pendleton, had shown that P.I. 178383 was resistant to all known race of both common bunt and dwarf bunt. The selection that was ultimately released as Moro was also found to be highly resistant to stripe rust in tests at Pendleton during 1961. It was also a club wheat that yielded almost as well as the leading wheat varieties with common-type heads. Moro was registered by Dr. Charles Rohde and seed was released to seed producers in 1965 (Rohde, 1966). Moro almost immediately became the most planted variety of winter wheat in all of the lowest rainfall regions of the Pacific Northwest (Schillinger et al. 2008). That occurred because Moro had a longer coleoptile than other varieties, which enabled it to emerge more efficiently from seed planted deeply into drier seedbeds. The release of Moro also occurred almost simultaneously with the development of the John Deere HZ deep-furrow drill, which allowed farmers to plant more deeply, into water preserved by the use of the rod-weeder (see Chapter 13). Within three years after release, Moro was planted on more than 20 percent of wheat acreage in all of Oregon and 16 percent of acreage in Washington. It maintained that status into the 1970s and, today, Moro is still planted in some very dry regions. Moro is always used as the ‘standard of excellence’ for comparisons of seedling emergence by newer wheat lines and varieties.

References:

Annual Reports from the Sherman and Pendleton Stations (Appendices 5 and 6)

Letters sent to or from the Station Superintendents

French, G. 1958. *The Golden Land: A History of Sherman County, Oregon*. Oregon Historical Society, Portland. 237 pages.

Hall, W. E. 1959. *History of Wheat Varieties in Sherman County*. Oregon Agr. Exp. Station Unpublished Mimeo. 3 pages.

Kronstad, W. E., C. R. Rohde, M. F. Kolding, and R. J. Metzger. 1978. Registration of Stephens wheat. Crop Science 18:1097.

Rohde, C. R. 1966. Registration of Moro wheat. Crop Science 6:502.

Scheuerman, R. D., and A. C. McGregor. 2013. *Harvest Heritage: Agricultural origins and heirloom crops of the Pacific Northwest*. Washington State University Press, Pullman. 186 pages.

Schillinger, W. F., and R. I. Papendick. 2008. Then and now: 125 years of dryland wheat farming in the Inland Pacific Northwest. Agronomy Journal 100 (Supplement):S166-S182. (Also published in 2009 as Washington State University Extension Manual EM004E. Pullman, Washington. 22 pages).

Vogel, O. A. 1952. The cooperative wheat improvement program in the Pacific Northwest. Pages 69-79. In. Proceedings of the Silver Anniversary Meeting of the Oregon Wheat Growers League. Portland, Oregon. December 4-6, 1952. 140 pages.

Vogel, O. A. 1964. Registration of Gaines wheat. Crop Science 4:116-117.

Vogel, O. A., R. E. Allan, and C. J. Peterson. 1963. Plant and performance characteristics of semidwarf winter wheats producing most efficiently in eastern Washington. Agronomy Journal 55:397-398.

Vogel, O. A., J. C. Craddock Jr., C. E. Muir, E. H. Everson, and C. R. Rohde. 1956. Semidwarf growth habit in winter wheat improvement for the Pacific Northwest. Agronomy Journal 48:76-78.

Chapter 8 - Forage Grasses and Legumes

Forage crops were of particular importance to the livestock industries when the Sherman Station was established. Variety trials were established during the first year of that station to evaluate the productivity of potential forage crops, including alfalfa, clover, grasses, field pea, vetch, oats, barley and sorghum. As local knowledge of these crops advanced, many different mixtures of crop species were examined for their productivity as grain hay, which was necessary to feed horses that were used as a power source for farming operations. There was also an on-going reliance on pasture and hay for commercial production of cattle, sheep and hogs. When tractors began to take the place of horses during the late 1920s, many farmers continued to use work horses for more than a decade. Some tasks were more efficient with the use of horses rather than with the earliest tractors. Both horses and a tractor were used for tillage, planting and harvesting operations during the earliest years of the Pendleton Station.

During recent years, the emphasis on forage grasses and legumes has become oriented toward evaluation of these crops as potential feedstock for production of biofuel. An overview of the most important tests and findings with forage crops at the dryland research stations is presented.

Forage grasses

Investigations began at the Sherman Station during 1911 with the planting of nine forage grass species and a date-of-planting study for alfalfa. Those experiments were established by Mr. Harry Umberger, the first Superintendent. The experimental design and treatments were determined in collaboration with superintendents of existing dryland experiment stations near Nephi, Utah, and Philbrook, Montana (near modern-day Moccasin). The trial at Moro was a modification of forage entries that were known to be working well at the other stations.

When David Stephens became the Superintendent of the Sherman Station, in 1912, he immediately began planting more forage trials each successive year, and continued to evaluate the older stands for persistence and many agronomic qualities. In the Station's 1912 Annual Report, Stephens stated that "*The forage crop problem in eastern Oregon is one that deserves a great deal of attention. Formerly an open range for sheep and cattle, agricultural operations in this vast area are now almost exclusively confined to wheat raising and the number of livestock has gradually decreased until in recent years the local butchers in the small towns find it exceedingly difficult to get enough beef and mutton to supply the meagre local demand. It is not at all uncommon to find farmers who buy their dairy products rather than make them. … Any kind of forage crop which would give fairly good results for hay or for pasture and at the same time have a beneficial effect on the soil for succeeding grain crops, would prove of inestimable value to the farmers of this section of Oregon*." Stephens went on to report that the "*The work with forage crops is in cooperation with the Office of Forage Crop Investigations of the Department of Agriculture*."

The forage crop research was scaled down in 1920, in response to the elimination of funds from by the Office of Forage Crop Investigations. Only the work with field pea was continued at the Sherman Station. David Stephens reported that this was an important loss because no hay crop had yet been identified that could compete with grain production. Alfalfa was disappointing because it didn't produce enough forage and also reduced productivity of the following grain crop. He stated that there was still a need to find suitable permanent pasture crops for large areas of land that were "*entirely unsuited to cereal production.*"

The station at Pendleton became established at a time in which there was an extended period of poor wheat crops at Moro as well as at Pendleton. For example, the weather was unfavorable for crop growth at the Sherman Station for five consecutive years from 1929 to 1933. Yields throughout the region were much below normal during those years. With the low wheat yields as well as unprecedented low prices, the financial situation of many farmers was worse than at any time since 1900. The Sherman Station Annual Report for 1932 stated that "*Farmers who expanded and incurred debts during the period of high wheat prices are now placed in a highly disadvantageous position because crop returns have not been sufficiently high during the last two years to pay interest charges and taxes*." Those circumstances led farmers to become much more interested in planting forage crops. Scientists at both dryland experiment stations planted rather large forage experiments beginning in 1931. The plantings included many native grasses in both pure stands and as different blends of grasses, alfalfa and sweet clover.

In the fall of 1932, Dave Stephens made a collection of several native grasses and planted the seed into a nursery at the Sherman Station. Stephens immediately started collecting agronomic performance data for that and other selections. The grass stands were evaluated through at least 1941 for their capacity to produce seed and forage, and for their ability to survive and to compete with weeds. One of the grasses collected by Stephens was from a stand of native grass between Moro and Grass Valley. That selection was ultimately registered as 'Sherman Big Bluegrass,' as discussed later.

Stephens wrote in the Sherman Station's 1933 report that "*There is an urgent need for better dry land grasses and for information about how low-yielding wheat lands can best be put back to grass.*" He acted upon that insight in 1935 by formalizing relationships between the USDA-SCS and the Sherman and Pendleton stations. New nurseries containing 126 native grasses were planted at both stations during 1935, and the SCS personnel collected another sample from the stand of bluegrass initially sampled by Stephens in 1932. Agronomic data was collected in collaboration with the SCS, and was reported in a separate summary prepared by Mr. Virgil B. Hawk, Manager of Outlying Nurseries, USDA-SCS, Pullman, WA (Hawk, 1938). The nursery was monitored closely for seed yield, longevity of adequate stand, and ratings of the value of the grasses for pasture and for controlling erosion, particularly on steeper slopes.

Grass nursery seeded in 1935 (photographed in 1942)

Grass nursery in 1939 (Sherman Big Bluegrass is at right)

The 1935 nursery was supplemented by planting another 150 rows of grasses in 1936, and another 90 rows in 1937. The 1937 Sherman Station Report listed 366 forage plant entries, including scientific name, common name, accession number, source, and date planted. Large acreages were required to test all of these grasses. In 1940, Merrill Oveson reported that the old grass nurseries were renovated and expanded again. Another 46 different grasses were planted into 6 × 40 foot plots, still under the management of Virgil Hawk. In the 1938 Annual Report, it was stated "*Poa ampla was again one of the highest yielding grasses in this nursery in both seed and forage production*." During that same year, Virgil Hawk published a 7-page mimeographed "*Summary of Value of Grasses and Legumes Under Moro Conditions.*" The bulletin discussed attributes and weaknesses for each of a long list of grasses. Hawk stated that "*Mr. Stephens was one of the first to recognize the value of big bluegrass and was instrumental in its promotion*." This grass became registered as 'Sherman Big Bluegrass' in 1945 (Schwendiman, 1972). The release showed that it "*was collected from native vegetation near Moro, Sherman County, OR, by D. E. Stephens, Superintendent of the Sherman Branch Experiment Station, Moro, in 1932*." The grass was tested for as many as 40 years at the Sherman Station and continues to maintain its' popularity as a remarkable conservation restoration grass that is known for efficient and functional roadside plantings. The stands are excellent and are preferentially grazed by domestic animals as well as by wildlife.

Crested wheatgrass was the most successful of the dryland grasses during the early trials. This species was therefore planted on a 4-acre parcel with the steepest slopes. The scientists quickly observed that the crested wheatgrass almost totally stopped water erosion and at the same time captured soil from the fallow land above it. The station staff therefore planted another 20 acres to crested wheatgrass and harvested it as a seed crop except during drought years. After a number of years they cultivated a small area and planted winter wheat. This was continued over a period of four years. They measured the productivity of wheat for each successive year after the plantings of crested wheatgrass were cultivated and returned to plantings of winter wheat.

Merrill Oveson, Superintendent of the Sherman Station, stated in 1940 that about 150,000 acres of wheat land in eastern Oregon was growing grass as a soil building crop under the Agricultural Adjustment

Act (AAA). The AAA was a component of the New Deal program that sought to raise crop prices by lowering production, which the government achieved by paying farmers to leave a certain amount of every acre of land unseeded. Oveson predicted that when payments under the AAA program were terminated, much of that land would be reseeded to wheat. He emphasized the need for more research to find the best methods that would allow those transitions to be economically feasible. Toward that end, another experiment was planted in 1940 and was expected to be continued for about five years, whereupon wheat would be grown and the wheat yields and soil qualities compared across previous treatments. The treatments included a planting of alfalfa alone, crested wheatgrass alone, wheat alone, or a mixture of alfalfa and crested wheatgrass.

By 1942, at the Sherman Station, there were 156 genera and species of forage grasses and legumes remaining from plantings made between 1935 and 1940. Some of the plantings contained mixtures of alfalfa and crested wheatgrass, and the mixtures were compared with plantings of each of the components of the mixture. Protein contents of the grasses were measured during 1941.

Large areas continued to be devoted to the testing of forage crops even during the years of labor shortages due to World War II. In 1944 the trials included perennial grasses and legumes in nursery rows, solid seedings of bunch grasses and sod-forming grasses alone and in combinations, larger seedings of promising grasses on shallow ground, mixtures of bunch grasses with alfalfa to determine effects on root development and improvement of soil fertility, and comparisons of forage grasses and alfalfa either alone or in mixtures. Data were collected to determine forage yields and protein contents. But the data for forage crops tests was kept to a minimum during the war. Attrition continued to reduce the number of forage plots that survived in trials planted from 1935 to 1937. The species that were still surviving in 1944 were mostly limited to those already known to be native to the Pacific Northwest, including species or varieties of *Poa* (9 entries), *Elymus* (6), *Agropyron* (9), and *Bromus* (2). Heavy weed competition was a key factor leading to deterioration of those strains and varieties that were less adapted to the local environment. Notes were taken of plot yields and also of the percentage of each plot occupied by downy brome (cheatgrass; *Bromus tectorum*). The best adapted varieties had very little cheatgrass. Seeded varieties were very thin in deteriorated plots, which had become dominated by cheatgrass. Oveson, in the 1944 Sherman Station Annual Report, stated that "*It is questionable that even with careful controlled grazing the native grasses will be able to establish new stands where the cheat has become well established*." During the fall, after all the varieties were mature and dry, the work horses were allowed to graze the forage plots and notes were taken of the grazing preferences. The forage on some varieties was totally consumed and other varieties were left virtually untouched after the first samplings by the horses.

During 1945, the best forage yields from grasses planted at the Sherman Station during 1940 and 1941 were obtained from crested wheatgrass and big bluegrass. Higher hay yields averaged over five years were obtained from the mixture of alfalfa and crested wheatgrass, as compared to pure stands of either component. Data were collected and the annual and long-term average seed and forage yields were reported routinely until 1948. The last of the old grass plantings were plowed after the 1949 harvest, and a new grass nursery with 20 varieties and/or species (including Sherman Big Bluegrass) was planted at both stations during the fall of 1949. The summary of the old nurseries were reported separately by Jack Woods, the new Manager of the Outlying Nursery Division of the USDA-SCS in Pullman.

Forages were also among the first crops studied at the Pendleton Station. At least two forage trials were planted during 1931 and were harvested to determine forage yields for many years. One was an alfalfa variety trial and the other was a comparison of 19 pure stands or blends of grasses, alfalfa and sweet clover. Those trials were planted as part of the program of the USDA Division of Forage Crops and Diseases. Results were still being published in the 1936 Annual Report from the Pendleton Station.

Additional forage nurseries were periodically planted through at least 1953. Some of those trials were at the Pendleton Station and some were at the King Pilot Farm (see Chapter 5). Merrill Oveson, in the 1953 Annual Report, provided detailed data and summaries from research on a forage grass nursery (20 entries) planted in 1949. Sherman Big Bluegrass was the top yielder at the Pendleton Station in 1953 (at 1,830 pound/acre) and was among the top four yielders for the four-year average. In 1952, they established grass seed production experiments with 24 blocks of orchard and brome grasses at the Pendleton Station, and a comparison of 33 grasses and alfalfa treatments at the King Pilot Farm. Replicated trials planted at the Pendleton Station in 1953 included one with 20 varieties and strains of wheatgrasses, and another with 16 varieties of alfalfa plus five more varieties that were planted into larger plots for observations on the longevity of the stands.

The 1955 Annual Report from the Pendleton Station reported results from 11 on-going forage crop experiments. At all locations, Sherman Big Bluegrass continued to be among the best-producing forage species. At the King Pilot Farm, in the trial planted in 1952, the inclusion of alfalfa in the mixture had increased the productivity of the wheatgrasses. During 1955, at the Pendleton Station, four new trials were established to compare varieties of 15 bromegrass varieties, 9 orchard grass varieties, 20 wheat grass varieties, and 21 alfalfa varieties. The alfalfa nursery was also established at the Crow Pilot Farm.

Yields of forage grasses and mixtures planted in 1949 were still being reported in the 1957 and 1958 Annual Reports from the Pendleton Station. Grasses that had either disappeared from, or now dominated, the mixtures in which they had been planted were identified, showing the selective competitiveness of the various species a period of eight years. Almost all of the alfalfa had disappeared from the grass-alfalfa mixtures at the King Pilot Farm, after only five years. Likewise, when originally planted as mixtures, sheep fescue had already eliminated the crested wheatgrass and, in other mixtures, the wheatgrass had eliminated the Camby bluegrass, bulbous bluegrass, and hard fescue. Some plots were identified because the grasses or alfalfa had failed to compete well with an incursion of cheatgrass. The reports in 1957, 1958 and 1961 identified the grasses that were still outstanding performers in these nurseries (hard fescue, sheep fescue, and *Agropyron intermedium*, *A. amurence*, *A. inerme*, and *A. spicatum*), those that yielded very well during the early years but were almost completely replaced by other grasses or weeds during a period of eight years (*A. sibiricum* and *Poa ampla*), and those grasses that became badly infested with cheatgrass and other weeds (*Elymus junceus* and *E. condensatus*).

<u>Forage Crops Testing at Moro</u>

1. Tested many forage legumes, grasses and cereal hays from 1911 until 1975
2. Collaborated very closely with the USDA Office of Forage Crop Investigations and the SCS
3. Peas grown annually were most profitable forage crop but did not compete economically with wheat
4. Refined the early planting and harvesting techniques for peas, alfalfa and hairy vetch
5. Demonstrated the value of crested wheatgrass plantings to eliminate soil erosion on steep slopes
6. Participated in the development and release of numerous crested wheatgrass selections and varieties
7. Collected the original strain of *Poa ampla* that was then developed and released as 'Sherman Big Bluegrass'

In the 1961 Pendleton Station Annual Report, Merrill Oveson and Laurn Beutler presented summary tables for all potential new crops tested at various locations, the number of years in which they were tested, and the estimated gross economic return from those crops. The crops they considered to have potential commercial value in the dryland area (12 to 18 inches of rainfall) included several forage crops (*Agropyron*, *Agropyron* plus alfalfa, *Festuca*, *Festuca* with alfalfa, and 13 other grass species or lines) and several grass seed crops (*Agropyron*, orchard grass, brome grass, alta fescue, pubescent wheat grass, and canary grass).

The USDA-SCS once again collected forage yields from the grass nursery and row spacing experiment during 1962. Sherman big bluegrass was the highest yielding variety at the Sherman Station, followed closely by Whitman intermediate wheatgrass and Nordan crested wheatgrass. After being fertilized with 40 pound of N/acre during 1962, yields of Sherman big bluegrass were increased from 840 pound/acre to 2,147 pound/acre. At the Pendleton Station, Sherman Big Bluegrass also continued to be among the best forage species. Similar results were measured for the forage grass nursery at the King Pilot Farm, established near Helix in 1950. Results for another 10 forage trials with grasses, alfalfa, or sweet clover were also reported in 1962; those trials were placed at locations with annual precipitations ranging from 12 to 18 inches.

The close relationship between the Sherman Station and the USDA-SCS continued for about 40 years after being formalized in 1935. The collaboration continued until at least the mid-1970s. An in-depth history of that collaborative effort was published by Schwendiman (1976). He described the history of the Sherman Station and its primary staff, maps of vegetation and soils across Oregon, and summaries of the grasses tested at the Sherman Station. The bulletin was illustrated by images of the Station and of the SCS team leader, Virgil Hawk, evaluating a stand of Sherman big bluegrass on the Sherman Station. Another photo showed a 1940 image of the site where Sherman big bluegrass was originally collected at the site between Moro and Grass Valley, along with the notation that "*this productive stand still persists (1974)*." Development of Sherman big bluegrass and crested wheatgrasses are among the key success stories from early research at the Sherman Station. Schwendiman (1976) stated that "*The oldest surviving planting of Crested wheatgrass in the United Stated today exists on the Moro Station. It was seeded in 1914. Some of the original rows can still be seen*." Today, Sherman big bluegrass is recognized as a long-lived, perennial bunchgrass with distinctly blue leaves and a large seed head. This grass is now widely used for rangeland seedings, roadside and other critical area stabilization, retirement of cropland, reclamation of mine tailing soils, habitat for upland wildlife, and production of dryland hay in areas receiving as little as nine inches of annual precipitation.

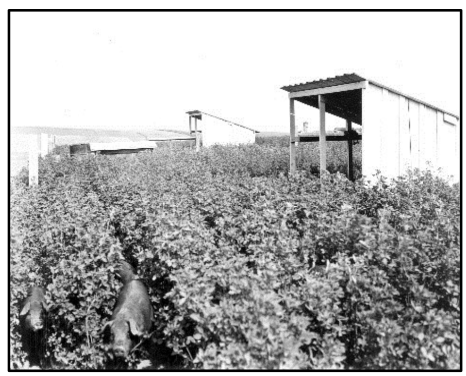
Periodically, studies have been conducted with cereals produced for the purpose of cutting them for hay. As an example, during 1942, 11 varieties of winter wheat, spring wheat, spring barley, and spring oat were tested for efficiency in producing cereal hay for livestock feeding. Although forage grasses and cereals were of immense importance particularly during the earlier years, they have not been an emphasis of research at the either of the dryland research stations during recent years.

Forage Legumes

Legumes can be of great value as feed, food, or green manure crops. The main forage legumes of potential economic importance in dryland production systems include field pea, hairy vetch, sweet clover and alfalfa. Each of these crops were tested at the Sherman and Pendleton stations.

In the 1911 Sherman Station Annual Report, Harry Umberger stated "*The work on peas is one of the most important at the station. While they are grown scarcely at all in this section, there are two general reasons why the crop is certain to establish itself permanently: First, in the continuous production of grain it will be necessary finally to either use a commercial fertilizer to renew the constantly depleted soil fertility, or to turn to some crop which will enrich the soil, and if this can be done by some crop which will be profitable for purposes other than the fertility it supplies, a greater profit to the farmer will result. Second, if a row crop can be utilized which will require intertillage during part of the season, it is probable that the acreage of summer fallow may accordingly be cut down. Peas answer these requirements and at the same time furnish a nitrogenous feed, which is greatly needed for stock feeding purposes. By the use of peas for pasture and grain, in addition to barley, it is probable that pork production may be made an important feature in eastern Oregon agriculture. The fact that peas require early cultivation and are removed early in the season should make wheat production following them as profitable as on summer fallow.*" Regarding vetches: "*The trial with different kinds of vetch showed wide differences to withstand the adverse conditions of 1911. They are worthy of further trial as they offer a possibility of growing a leguminous hay crop … and also for a green manure crop, such as a mixture of rye and winter vetch or oats and common vetch*."

Mowing alfalfa at Sherman Station - 1915



Hogs in a clover-feeding experiment at the Sherman Station - 1912

As stated earlier, Dave Stephens re-emphasized the need for forage grasses and legumes in the region during 1912. Six acres were seeded to field pea at the Sherman Station in 1912. The goal was to determine the value of field pea as a hog pasture. They enclosed the field by constructing a fence. Two lots of hogs were purchased for the first experiment; one lot was purchased locally and the second lot was purchased from the Animal Husbandry Department at Corvallis. Experiments included measurements of rate of weight gain and profitability.

Research on forage legumes was strongly expanded when the Sherman Station developed a collaborative forage research program with the USDA-SCS during 1914. Station scientists concluded in 1915 that "*Field peas have proved to be the most profitable of all the forage crops tested on the substation. The crop is a new one in the Columbia Basin of Oregon. At the present time, however, the experiment* *stations and cooperators cannot grow enough seed to supply the demand. The requests for seed exhausted the station's 1915 crop before the close of the year*."

The scientists found that the best yields of alfalfa, sweet clover and field pea were achieved when these crops were planted into widely-spaced rows. Weeds were controlled by early-season cultivation between the rows. However, with that planting system, too much soil was picked up by the hay rake, which often reduced the quality of the hay. For peas, they therefore refined the harvesting techniques to improve the harvest efficiency and seed quality. They refined the time of mowing, began curing cut plants in shock rows running parallel to the direction of prevailing winds, and prevented cracking by reducing the speed of the cylinder and removing the concave teeth. The scientists at the Sherman Station also developed a dichotomous key to distinguish the 22 pea varieties that were grown on the station during 1915. The use of the key involved determining flower color, leaf axil color, smoothness of seed coat, seed color, hilum color, plant height, leaflet size, pod size and seed size.

As stated earlier, the forage crop research was reduced in 1920 in response to the loss of funding from the Office of Forage Crop Investigations. Only the work with field pea was continued. The focus on peas continued over the years, particularly as part of the rotation experiments that will be discussed in a separate chapter.

Also mentioned previously, 19 pure stands and mixtures of grasses, alfalfa and sweet clover were planted at the Sherman and Pendleton stations during 1931. During the same year, replicated trials with six varieties of alfalfa were started at both stations. Those nurseries continued to be sampled for forage yield, weed suppression, and stand longevity until the early 1950s. During the 1940s there was a major resurgence of research on crops that could potentially broaden the opportunities for farmers throughout the region. Four varieties of field pea were sown into replicated plots where the peas were planted either into solid-seeded plots or into rows. Alfalfa was also tested for seed production, using three row spacings and three methods of handling the alfalfa harvest.

Pea, alfalfa and other forage legumes produced highest yields when planted in widely-spaced rows

Prior to 1940, throughout the region, Austrian pea had always been grown as a spring-seeded crop. In the fall of 1940 it was planted during the fall. During a relatively mild winter, the Austrian pea produced three times more yield than the same variety planted during the spring. Plantings during the next several years were made during both spring and fall to determine the extent of winter hardiness. Austrian pea proved to be a crop of great importance when it was planted during the fall but it was considered unsuccessful as a spring crop because it produced 25 percent less yield than other types of spring peas.

A new alfalfa variety trial with 16 entries was established during 1953. By 1954, Merrill Oveson, Superintendent of the Pendleton Station, was reporting data from 11 forage crop experiments. During the 1960s, Laurn Beutler, an agronomist at the Pendleton Station, spent several years to screen the world collection of alfalfa varieties at the Umatilla Branch Experiment Station at Hermiston. He was assisted in that work by Dr. Rod Frakes, an alfalfa breeder at Oregon State College, and by Mr. Tom Davidson, Superintendent of the Umatilla Station.

Merrill Oveson, in the 1950 Annual Report for the Pendleton Station, summarized results of a 16-year experiment initiated during 1942. Alfalfa was planted and grown in four blocks for four years. The blocks of alfalfa were staggered so they were established during four successive years so that weather would not be a complicating factor, as compared to starting all blocks of alfalfa at the same time. The wheat crops that followed the alfalfa were therefore also offset so that the first, second, third, etc. wheat crop was offset with respect to year. The experiment examined the lasting effects of four years of alfalfa as a soil building crop, followed by a prolonged period of winter wheat rotated with cultivated fallow. The goal was to determine when the benefits of the alfalfa crop would no longer be measurable. A farmer following this rotation would need to have livestock to utilize the forage produced because a quarter of the land would always be in the soil-building phase. The four forage crops produced during four years would more than offset the income from the two wheat crops lost in this rotation. Yields of wheat during the first year after alfalfa was taken out were higher than for wheat following regular fallow during three of four years. The exception occurred during a year in which the weather was particularly dry and hot. During the second through fifth wheat crops, the wheat following four years of alfalfa always produced more than wheat growing in blocks where alfalfa had not been produced. Positive benefits from the alfalfa treatment therefore continued to be measurable for 10 years (the fifth wheat crop) after the alfalfa had been taken out at Pendleton.

Additional information about research on peas, sweet clover and alfalfa is presented in Chapter 12.

Forages for Biofuel Production

During the 21st century, interest in forage production by scientists at the dryland research centers has attained an emphasis for a purpose other than producing feed for animals. USDA-ARS scientists evaluated forages that could be produced as buffers along streams, to protect water quality and suppress growth of weeds, and harvested as lignocellulosic feedstock to produce biofuel.

Dr. John Williams coordinated evaluations of tall wheatgrass alone, alfalfa alone, small grains, and mixtures of tall wheatgrass and alfalfa at six Oregon and Washington sites that represented three precipitation zones. Each plot was 12 × 165 feet and each treatment was replicated four times at each site. Samplings were made annually for four years. Measurements included forage mass, species composition, lignocellulose yield, soil water, rainfall and temperature. Methods for collecting samples varied depending upon conditions at each site

Harvesting forages to determine their potential as biofuel feedstock;
workers included David Robertson (gray shirt) and Dr. John Williams (white shirt)

each year. At each site, perennial plantings of tall wheatgrass and a mixture of tall wheatgrass with alfalfa produced two to three times more forage biomass than dryland alfalfa or small grains (Williams et al., 2015). The two highest-producing treatments also provided the greatest competition against invasive annual weed species.

Dr. Daniel Long also coordinated evaluations of switchgrass and oilseeds as potential biofuel feedstock. Research on oilseeds is discussed in Chapter 9. At the Pendleton Station, Dr. Long and associates compared biomass productivity of perennial switchgrass and annual winter wheat in replicated plots over a period of six years. These crops were produced under irrigation to simulate low, medium and high precipitation levels. Samples were collected to measure above-ground biomass, soil organic matter changes to six-inch depth, soil nutrient dynamics, and evolution of carbon dioxide from soil, and other characteristics of soil. The scientists determined that winter wheat produced more biomass than switchgrass under each of the watering regimes (Chatterjee et al., 2018). As expected, each crop species produced greater amounts of biomass as the level of watering was increased. Interestingly, during the five years of cropping, at each level of watering, winter wheat also resulted in a greater increase of soil organic carbon compared to switchgrass. Major changes in soil nutrient dynamics occurred for switchgrass compared to winter wheat (Chatterjee et al., 2013). The intensity of nitrogen mineralization and increase in soil microbial biomass carbon were increased more by switchgrass than wheat in the two higher watering regimes. This caused various shifts in the soil carbon-to-nitrogen ratio, depending upon watering regime and soil depth.

***References*:**

Annual Reports from the Sherman and Pendleton Stations (Appendices 5 and 6)

Letters sent to or from the Station Superintendents

Chatterjee, A., D. S. Long, and F. J. Pierce. 2013. Switchgrass influences on soil biogeochemical processes in the dryland region of the Pacific Northwest. Communications in Soil Science and Plant Analysis 44:2314-2326.

Chatterjee, A., D. S. Long, and F. J. Pierce. 2018. Change in soil organic carbon after five years of continuous winter wheat or switchgrass. Soil Science Society of America Journal 82:332-342.

Hawk, V.B. 1938. Annual Report of the Moro Outlying Nursery. U.S.D.A., Soil Conservation Service, Pullman, Washington. 56 pages.

Schwendiman, J. L. 1972. Registration of Sherman big bluegrass. Crop Science 12:125

Schwendiman, J. L. 1976. Grasses and Legumes for Conservation Use in Semiarid Wheat-fallow Areas of Eastern Oregon. USDA Soil Conservation Service, Portland, Oregon. 102 pages.

Williams, J. D., D. S. Robertson, and S. B. Wuest. 2015. Biofuel feedstock production potential in stream buffers of the inland Pacific Northwest: Productivity and management issues with invasive plants. Journal of Soil and Water Conservation 70:156-169.

Chapter 9 - Other Crops and Organic Agricultural Systems

Improvement of crops other than wheat, barley and oats has also been a focus of the Sherman Station and Pendleton Station since their inception. More than 100 types of crops have been investigated by scientists at these stations, with some crops being tested periodically or repeatedly for long periods of time. A listing of most of those crops is shown near the end of this chapter. Those crops were examined for differing purposes. Some were intended to 1) provide forage or grain for animals, 2) stabilize soil, 3) produce cash crops or green manures to improve farm profitability and/or improve soil health, or 4) identify novelty crops that could be grown as small acreages to meet the needs of niche markets.

Forage crops were of particular importance to the livestock industries when the Sherman Station was established. There was an on-going reliance on horses, mules and oxen for power, and an interest in commercial production of cattle and hogs in the region. In 1911, during the first year of experimentation at the Sherman Station, variety trials were established to evaluate the productivity of flax, corn, grain sorghum, alfalfa, clover, grasses, potato, kale, rape, field pea, vetch, and crops of oats, barley and sorghum cut for hay. A date-of-planting trial was also established for alfalfa. These studies soon incorporated tests of emmer, spelt and rye, and many different mixtures of grain hay. The tests at Moro established the protocols for similarly intensive investigations at the Pendleton Station and off-station locations. Some of the most important tests and findings are discussed.

<u>Tests of Other Crops at Moro</u>

1. Extensive work was conducted to develop rotational crops; especially potato, field pea, safflower, corn, mustard (rape), soybean, and rubber crops (dandelion and guayule).
2. Potato was initially a crop that was as profitable as winter wheat.
3. Other crops tested included lentil, chickpea, garden pea, hairy vetch, bean, castor bean, sunflower, flax, rye, grain sorghum, emmer, spelt, coriander, anise, fennel, and caraway.

Food and Feed Legumes

Legumes can be of great value in all cropping systems. Where economically feasible, they can be grown as feed, food or green-manure crops. The main food legumes of potential importance in the dryland production systems include green pea, soybean and dry bean. While all of these potential rotational crops have been tested at the stations, the following discussion is limited to studies with crops that provided the greatest promise for contributing to the farm economy in the regions.

Peas (Field and Canning)

Forage crop research flourished during the first decade at the Sherman Station but was reduced in 1920 in response to a termination of funding from the USDA Office of Forage Crop Investigations. Only the work with field pea was continued. Over the histories of the Sherman and Pendleton stations, varieties of peas have been screened periodically and peas have been a component of most crop rotation experiments. Field pea was a particularly important component of some treatments of the crop rotation experiments that were established when each of the stations were established.

During the mid-1930s the pea industry particularly in the Pendleton area was shifting from production of dry peas to canning peas. Yields of wheat after canning pea were not reduced as much as after dry peas. The difference was thought to be that dry peas used all of the surface moisture and didn't allow mineralization of organic matter when the soil was dry. In contrast, canning pea is followed by immediate plowing while the soil is still moist, allowing the pea debris to mineralize before wheat is planted.

During the 1940s, the acreage of canning peas continued to expand into the Pendleton area and eastward as far as Dayton, Washington. Nearly 20 percent of the peas canned in the U.S. were being produced and processed in this area. Production of dry pea became minimal and was usually reserved for canning peas deemed to have become too mature for canning, or infested too heavily by weevils. Many growers adopted a 3- or 4-year rotation, with peas for two or three years and then a year of wheat. On the Pendleton Station, peas were grown annually for six years without any apparent disease. During the late 1940s, the Pendleton Station conducted very large on-station and off-station replicated experiments to examine productivity of 13 canning pea varieties on land amended or not amended with lime, and also treated with six types of fertilizers applied at three different rates. The amount of work on these experiments made it necessary to install a stationary pea viner at the Pendleton Station.

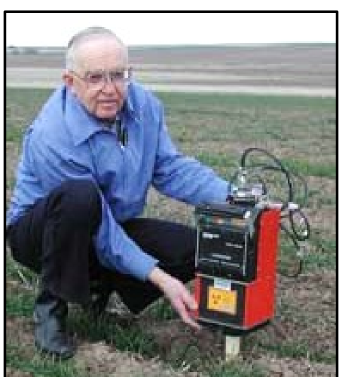
During the mid-1950s, at Pendleton, another extensive (30 replicated treatments) fertilizer experiment was conducted to study yield and maturity relationships with freezer peas. The fertilizers included various sources of nitrogen, phosphorus, potassium, sulfur, magnesium, zinc, boron, copper, manganese and molybdenum. Visual appearance was documented, and data were collected on five harvest dates (five successive days from June 26 to July 1) for green pea yield, vine yield, vine-pea ratio and pea sieve size. The results showed that fertilizers delayed the maturity date and stimulated vine growth much more than pea yield.

The station also planted three green pea fertilizer trials in the Spofford, Athena and Pendleton areas, using the same treatments that were being tested in Washington by a consortium consisting of Washington State College, Libby, Bird's Eye, and Walla Walla Canning Company. A fertilizer application timing experiment (fall vs. spring) for production of green peas was also planted near Spofford.

Stationary pea viner at the Pendleton Station (1993)

From the late-1960s until the mid-1980s, scientists at the Pendleton Station again tested peas under irrigated and dryland conditions. Those tests were conducted on the Pendleton Station as well as at commercial farms near Adams and Umapine, OR. Roland Schwanke, Vance Pumphrey, and Drs. Robert Ramig and Raymond Allmaras examined the effects of irrigation on growth, yield and quality of green peas. They also examined irrigation scheduling, growth hormone testing, nitrogen fertilizer rates, and row and plant spacing. They monitored soil water content at five depths using three different methods; Bouyoucos soil blocks, tensiometers, and gravimetric soil samples. The scientists also established relationships that became critically important to growers as well as processors, such as water-use efficiency data for crop yields, and the relationship between yield and tenderness factors, particularly as that relationship is affected by precipitation, soil moisture, and excess heat during the growing season. In 1970, Pumphrey reported that "*Irrigating wheat and peas along the foothills of the Blue Mountains in Umatilla County has not been an unqualified financial success. Yield increases from irrigation are obtained, but the additional income above non-irrigated production may or may not meet all the additional costs. Interest continues in irrigation from at least two sources. (1) Present irrigation operators would like to increase their returns at least to a point where all costs can be paid and a respectable living obtained. (2) Many non-irrigating operators are experiencing financial stress and are wanting to know if changing to irrigated agriculture would reduce the financial stress being experienced*."

Based upon 20 years of research, in 1972, Vance Pumphrey made the following observations about relationships between pea yield and tenderometer readings at the Pendleton Station. Tenderometer readings on green processing pea increased very rapidly, with only a 3- to 6-day interval for peas to transition from being too immature to being too mature for freezing and canning. Soil moisture, air temperature, and wind all have a strong influence on how rapid the maturation occurs, and whether peas can be sold to processors or must be taken to dryness to sell as a dry pea, for which the income is much lower. For processing peas, the processors want a pea with a tenderometer reading of 95 to 100. In the research trials, the tenderometer readings went from 95 to 105 in slightly more than 24 hours. Pumphrey concluded that tenderometer readings had to be taken daily to be useful in scheduling harvest at the optimum level of maturation. Moreover, the relationship between yield and tenderometer reading made it essentially meaningless to measure yield because pea maturation stages were not all equal at the time the peas were harvested. He further concluded that year-to-year variability was too great for a meaningful relationship to be developed between yield and tenderometer readings.



F. Vance Pumphrey

During the 1980s, these scientists and Drs. Dale Wilkins and Steve Lund also established a strong collaborative relationship between the Pendleton Station and Dr. John Kraft's pea breeding program at the Irrigated Agricultural Research Center at Prosser, WA. Umatilla County Extension Agent Thomas Darnell became a key cooperator in Kraft's regional pea variety testing program. Most of the variety trials of local importance were conducted on commercial farms in the Milton-Freewater and Walla Walla areas. However, Kraft also screened as many as 164 breeding lines on the Pendleton Station. The scientists reported factors such as flowering date, maturity date, weekly water extraction at 1-foot depth increments, average daily water use, and seed yield. Kraft's research was very productive in that it produced varieties and breeding lines with combined resistances and/or tolerances to pea wilt (*Fusarium oxysporum* f. sp. *pisi* races 1, 2, 5 and 6), three root rots (*Fusarium solani* f. sp. *pisi*, *Pythium ultimum*, and *Aphanomyces eutiches*), vine rot (*Sclerotinia sclerotiorum*), and pea seedborne mosaic virus.

The extent of the collaboration with Kraft was very broad, in that it included emphasis on yields and quality of pea varieties, effects of soil tillage pans and incorporated wheat residue on pea yield and pea root growth and health, effects of soil amendments (lime and gypsum) and tillage on inoculum density of pea root pathogens such as *Pythium ultimum*, effects of various types of tillage (chisel plow or paraplow) or no-tillage on pea yield and root health, effects of plant spacing on pea yield, and efficiency of different types of seeding equipment for production of peas particularly in conservation tillage systems. Dr. Mark Siemens continued to evaluate seed drills for optimum production of peas in conservation tillage systems until the mid-2000s.

During the 1940s there was also a major resurgence of research to identify alternative crops that could potentially broaden the opportunities for wheat farmers. The growth and productivity of field pea varieties was re-examined in replicated plots sown either into solid-seeded plots or as a row crop. As many as four varieties were tested during individual years. Also, for the first time at the Sherman Station, experiments included evaluations of up to seven varieties of garden pea. Interest in peas waned during the late 1940s but screening of pea varieties again became a topic of experimentation under irrigated conditions at the Sherman Station during the late 1960s. Pea varieties were tested under irrigated conditions over a five-year period (1966-1970) 20-miles northeast of Wasco, OR, and over a 2-year period (1968-1969) at the Sherman Station. Jack McDermid concluded that canning pea, potato, sugar beet, dry bean and sudan grass were each "*crops that would produce an economic return with a suitable market outlet*." Thereafter, interest in pea waned once again in Sherman County.

Tests with Other Dryland Crops

1. At least 100 types of crops have been tested by scientists at the Sherman and Pendleton Stations since 1911.
2. In 1923, after 15 years of testing potential crop rotations at the Sherman Station, David Stephens concluded that "*the growing of winter wheat after fallow will likely for a long time remain the most popular method of growing this crop on the drier lands of eastern Oregon*." However, he also cautioned that "*the soil fertility problem incident to any one-crop system of farming may some time compel a change in the present wheat-fallow system now so universally practiced in eastern Oregon. Or such a change may be brought about by difficulty in controlling noxious weeds, insect pests, or wheat diseases*." These statements continue to be applicable in 2019. Testing of potential rotation crops continues.

Interest in pea research experienced a resurgence during the late 1990s and early 2000s. Newer varieties of fall-planted peas were examined at the Sherman Station during the late 1990s by County Agent Brian Tuck. This work became administered by Dr. Stephen Machado during the 2000s, and was duplicated for plantings at both dryland experiment stations. Machado and colleagues examined effects of planting dates and seeding rates. At Moro the optimal planting date was during mid-October and at Pendleton the optimal date was during mid-November. Depending upon the year and location, winter peas produced grain yields up to 3,000 pounds/acre and a plant biomass up to 5,500 pounds/acre. Fall-planted pea varieties produced as much as 1,900 pounds/acre more grain than spring-planted peas. Spring peas generally yielded less than 1,000 pounds/acre at Pendleton and 700 pounds/acre at Moro. However, during 2004, at Pendleton, each of the three spring pea varieties tested yielded about 3,000 pounds/acre. In his 2005 report, Machado provided recommendations for all phases of pea production in the dryland region.

Dr. Stephen Machado

Chickpea

The first evaluations of chickpea (garbanzo bean) occurred over a two-year period during the mid-1980s. For two years, Vance Pumphrey evaluated four types of edible seeded legumes (pea, lentil, chickpea and faba bean) for flowering date, maturity date, seed yield, average daily water use, and weekly water extraction from 1-foot depth intervals. He concluded that further research with chickpea was warranted but the climate at the Pendleton Station was not sufficiently favorable to justify further studies with lentil or faba bean. Of those crops, water extraction was least with pea and greatest with faba bean. Research on chickpea began in earnest during the 2000s, at a time when the closure of green pea processing plants in eastern Oregon forced growers to look for alternatives to the green pea formerly used in rotation with winter wheat in eastern Umatilla County. Dr. Stephen Machado coordinated comparisons of varieties, planting dates, row spacing, and seeding rates at two sites in Umatilla County and at the Sherman Station. Dr. Richard Smiley coordinated comparisons of seed treatment fungicides to provide protection from root diseases. Dr. Mark Siemens examined six different combine header designs to reduce losses of chickpea grains during harvest. Variables included guard density (single or double), short or long finger attachments to guards, an air reel, and a stripper header. Siemens determined that losses during harvest were almost entirely attributed to losses from the header, because there were minimal losses associated with the threshing, separating and cleaning operations. Data included the amount of grain lost from each header design, the overall combine yield, the value of the lost grain, and the cost to modify the header to that configuration.

Seven varieties of chickpea were tested by Machado during 2002 and 2003. He evaluated optimum seeding dates, row spacings and seeding rates for their effects on grain yield and market grade (grain size). Tests were conducted at the Pendleton and Sherman Stations, and at the Nibler Farm near Milton-Freewater. Yields up to 1,100 pounds/acre were produced in eastern Umatilla County and yields up to 900 pounds/acre were produced at Moro. Crops planted at row spacings of 6- and 12-inches were equally productive. Different varieties were identified as being most productive in low- versus higher-rainfall sites. Optimum seeding rates were identified for the different rainfall zones, and row spacing had no effect on productivity at any site. The optimum planting date for two Kabuli-type varieties occurred during early April. However, since the planting date had different effects on the size of grain produced, different varieties were recommended for different end-use priorities. 'Dwelley' produced larger seed when planted during early April and 'Sinaloa' produced larger seed when planted during late April or early May. Dr. Machado reported in 2004 a complex set of recommendations depending upon the variety planted, rainfall zone, and farmer-determined priority placed upon gross yield of beans versus the percentage of beans that would be graded into the highest-valued marketing classifications. As an example, 'Sinaloa' was suggested for production if the goal was to obtain both high bean yield and high percentage of Grade A beans in both high and low rainfall zones, and 'Myles' was suggested if the goal was only to produce the highest bean yield in both low and high rainfall zones. Myles produced high yields of feed and Grade C beans.

Machado determined that safflower produced greater yields than chickpea when averaged over a 3-year period at both Pendleton and Moro. In those tests, under both no-till and cultivated conditions, safflower produced more grain than chickpea, yellow mustard, lupin, millet, buckwheat, linola, flax, and sunflower.

Chickpea plants were affected by several fungal and viral diseases at all three test locations. Smiley demonstrated that fungicide seed treatments improved seedling emergence of grain yield by reducing Pythium damping-off. However, the seed treatments did not alter the incidence or severity of root disease on mature plants, and did not improve the market grade of beans produced. These and other agronomic and weed control studies with chickpea led to publication of a chickpea production guide in 2004 (Corp et al. 2004).

Soybean

The Sherman Station tested 35 varieties of soybean from 1941 until 1944. They emerged well but did not thrive due to cool spring temperatures. Then they took on new vigor with the onset of fall rain and started to produce seed, which matured very late. The early-maturing varieties were ripe by mid-September, medium-early varieties by late-September, and late varieties by late-October. The quality of beans was good. In 1944, "*the soybeans were a total failure again this year*" due to poor emergence, unfavorable growing conditions during the summer, and rabbit damage. The 1944 report went on to state that "*Soybeans have been grown for a number of years at the station, without ever producing a good crop as compared to* *crops from cereals*." It was decided that "*it seems advisable to discontinue spending further time and funds on this particular crop*." Newer varieties of soybeans were tested in the 1970s and again during the 2000s, leading to the same conclusion stated during the 1940s.

White (narrow-leaf) lupin

Three Mediterranean species of sweet (low-alkaloid) lupins are an important grain legume crop in Australia, Eastern Europe and the northcentral U.S. Blue lupin, white lupin and yellow lupin are primarily used as a protein source in livestock and poultry feeds, often as a substitute for soybean. Lupin contains similar protein to soybean, but less fat and more dietary fiber, amino acids and antioxidants. Brian Tuck, Sherman County Extension Agent, initiated tests at the Sherman Station and at the Bill Todd Farm during the early 1990s. In 1993, Tuck compared the performances of five spring-planted varieties and the effects of different seeding rates. During a wetter-than-normal spring, the spring-planted varieties produced from 1,412 to 1,838 pounds of dry grain/acre in the variety trial and up to 2,164 pounds/acre in the seeding rate experiment. It was noted that the lupins were injured from the same complex of root disease pathogens that affect pea crops in the region. Tuck's work continued with spring- and fall-planted lupin varieties but results were not reported.

Until about 2010, a succession of scientists continued to evaluate narrow-leaf lupin at the Sherman and Pendleton stations and at off-station locations throughout north-central Oregon. Scientists leading those investigations included Drs. Chengci Chen, Bill Payne, Dan Ball, Stephen Machado and Steve Petrie, each of whom were stationed at Pendleton. The tests included comparisons of varieties, seeding rates, weed control, and water use by lupin varieties. The varieties produced highly variable amounts of grain during some years. More uniform yields during some years, such as in 1999, led to yield ranges of 1,220 to 1,613 pounds/acre at Pendleton and 1,132 to 1,313 pounds/acre at Moro. Due to extreme drought during the spring of 1999, none of the varieties produced nearly as well at tests sites near Helix (256 to 951 pounds/acre), Lexington (0 to 189 pounds/acre) and Condon (0 to 425 pounds/acre). It was determined that lupin needed to be planted as early as possible, with highest yields and protein contents being achieved with plantings during mid-March. There was a rapid decline in yield and protein content from plantings made after the end of March. Satisfactory control of weeds such as Russian thistle and tarweed fiddleneck were achieved with some of the herbicide treatments examined by this research team. Lupin were found to be susceptible to the same array of root and stem pathogens that are known to attack peas in dryland fields of eastern Oregon.

Oilseed Crops

The primary oilseed crops tested at the dryland experiment stations include safflower, sunflower, canola, and mustard (rapeseed).

Safflower and sunflower

These crops were grown at the Sherman Station for the first time during 1940. The severe drought caused the safflower crop to mature early, with full bloom on July 12 and harvest on August 24. The plants did not lodge, shatter, or suffer from disease or insect pests, and the hot dry weather did not interfere with the setting of seed. It was concluded that further tests with safflower were warranted but that the potential for future production of sunflower was limited.

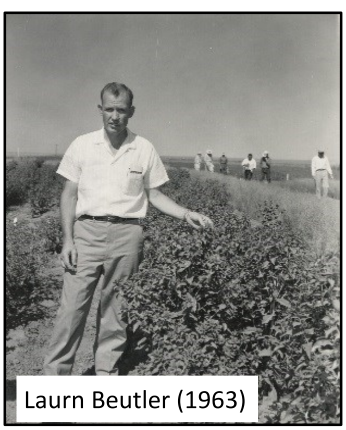
In 1941, the work with safflower was intensified at the Sherman Station and was also expanded to include seven off-station trials. Experiments included four safflower varieties planted on four different dates, and comparisons of types of drills, row spacing, and various settings on seed drills. Field mice ate so much of the seed for the April 1 planting that the stand was not harvested. Safflower was ready for harvest about a month later than wheat; August 17 vs July 15. Safflower yields at the seven off-station locations ranged from 4 to 27 bushels/acre. Off-station testing continued in 1942 but was curtailed in 1943 because of the labor shortage and curtailment of travel during the war. However, testing was continued on the Sherman Station. In the Annual Report for 1944, it was stated that "*While safflower has been one of the most promising crops which could take the place of wheat, it is questionable that it will ever be grown successfully in an area with as low summer rainfall as that obtained in eastern Oregon*." This statement foretold the experience with safflower during 1945, at which time the crop was a failure due to extreme rodent damage and contamination by dandelions.

By 1948, varieties of safflower had been grown in the nursery at Moro since 1940. During the latter years of those tests, the Sherman Station had been growing a regional safflower nursery distributed by the University of Nebraska. Varieties that had been grown for a longer period of time at the station were added into the regional nursery. Again, it was observed that safflower appeared to be the most promising substitute crop for the other grain crops in this area. Safflower's yield in pounds per acre was generally one-third that of wheat, during years of high as well as low yields. The oil content and test weight of safflower in this area was of higher quality than for other production areas. The 1948 Sherman Station Annual Report stated that "*Industry is just beginning to find a market for the oil and if wheat becomes unprofitable, safflower may prove to be suitable in this area*." In 1950, safflower in the regional nursery produced the best-ever yields at Moro. All except four varieties exceeded 1,000 pounds/acre. The test weights and the oil contents were also above the long-time average. While highly productive, the profit margin for safflower produced per acre was less than for wheat during 1951; assumptions were, spring wheat averages 30 bushels/acre and markets for $2.00/bu (gross $60/acre), versus safflower averaging 800 pound/acre and $6.25/cwt (gross $50/acre).

In 1954, the Sherman Station Annual Report indicated that "*With increased wheat acreage restrictions farmers have again sought a substitute crop to be grown on the wheat land of the Columbia Basin. Safflower varieties have been tested in nursery trials at the Moro Station since 1940. Interest was stimulated by a company in California seeking to expand their production area. With USDA's announcement that barley would be allowed on diverted areas most of the interest in safflower disappeared. While safflower production would fit rather well as far as needed machinery and equipment, tillage practices and methods of harvest are concerned, it poses additional problems for this wheat producing area. Safflower in this area yields only one-third to one-half the pounds per acre that winter wheat will yield. It is a poor weed competing crop and the land must be well prepared before seeding. There is less crop residue left on the ground after harvest so that the ground is more subject to erosion. Being a spring crop, seeding operations come at a time when farmers would prefer to be preparing their summer fallow for the next year's wheat crop*." Safflower also matures very late. Nevertheless, agronomic trials were continued to find ways to increase the profitability of safflower by improving weed control and oil yield by optimizing the rate of seeding, date of planting, soil preparation, and rate of fertilizer application.

Other problems also became apparent. The safflower nursery was accidentally sprayed with 2,4-D during 1959, resulting in abandonment of those experiments. With that exception in 1959, safflower testing for agronomic performance and oil quality and quantity had been conducted every year for two decades. Near the end of that testing period it was observed that "*some unknown factor has been steadily decreasing the yields such that the average yields during the past five years are now only half of what they were during the first five years.*" The yield decline was first noticed in 1954, and the reason for the decline could not be identified.

Studies on safflower were mostly performed near Pendleton during the late 1950s through 1970s. Laurn Beutler, Roland Schwanke, Vance Pumphrey, and others conducted safflower studies over a 10-year period at three locations; Pendleton Station, Crow Pilot Farm near Weston, and King Pilot Farm near Helix. In 1962, they reported up to five years of data for up to 15 varieties. Yields at the King Pilot Farm were comparable to the yields in Sherman County, under approximately the same annual precipitation regimes. Beutler also tested about 700 plant introduction lines for winter hardiness, in cooperation with the USDA-SCS Plant Introduction Station, at Pullman, WA. A few lines were notable for their ability to survive when the temperature dipped to 6ºF without snow cover. Eight varieties of sunflower from Canada were also tested in the plant introduction nurseries. The sunflowers matured so late that they ran out of water and wilted, but were still too immature to harvest at the end of October, at which time it began to rain.


Laurn Beutler (1963)

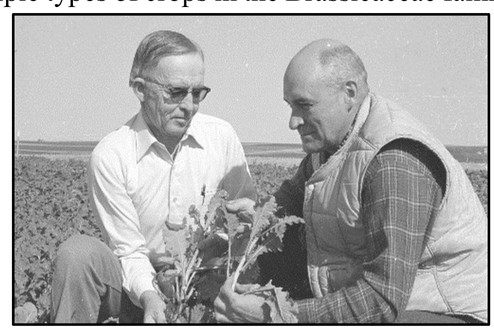
More recent research on safflower at Moro and Pendleton was conducted by OSU scientists Drs. Steve Petrie, Don Wysocki, Stephen Machado and Richard Smiley. In wide-ranging and more specific studies, safflower was the most productive of eight crops tested under both no-till and cultivated conditions over a 3-year period at the Pendleton and Sherman Stations. The tested crops included safflower, yellow mustard, lupin, millet, buckwheat, linola, flax and sunflower. These tests included a comparison of 17 varieties or lines of spring-planted safflower at both locations. Yields varied from 665 to 1,500 pound/acre at Pendleton and from 733 to 1,400 pound/acre at Moro. Only a few plants of fall-planted safflower survived through the winter, and stands during the spring and summer were too sparse to be harvested. The spring-planted safflower tended to yield better at Pendleton when planted without tillage. At Moro, safflower produced better if it followed a fallow year rather than a wheat crop. Varieties varied in oil content and several varieties were specifically noted for having high oil yields. Safflower was noted as a crop that sharply reduced populations of root-lesion nematodes that caused yield reductions in wheat crops. Sunflower also produced well at Moro during the more-recent tests.

Canola, mustard and camelina

Early screenings of oilseed rape (mustard) at the Sherman Station showed that the crop had some potential as a possible rotation with small grain crops. Studies of yellow mustard were expanded in 1941 to include greater testing on the Sherman Station and seven off-station locations. The trials included date-of-seeding tests for two varieties, and comparisons of types of drills and the settings on drills. Mustard yields at the off-station trials ranged from 552 to 1,166 pounds/acre. Several farmers also planted commercial fields of mustard, with yields ranging from 100 to 1,000 pounds/acre. Tests of condiment mustard crops were discontinued during 1943 due to labor shortages during the war. Two decades later, during the 1960s, the testing of these crops resumed and has continued nearly continuously to the present time.

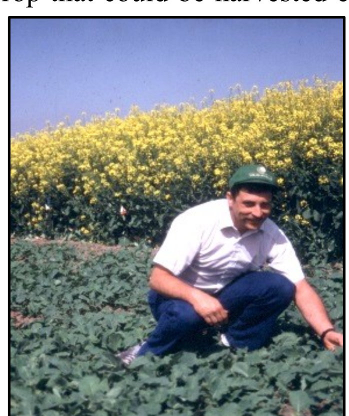
During the 1960s, Laurn Beutler tested eight varieties of mustard and rapeseed from Montana State University. Those tests continued over a period of three years at three locations; Pendleton Station, Crow Pilot Farm and King Pilot Farm. Beutler examined cultural management practices such as a date-of-seeding and traits such as winter hardiness and grain yield. All varieties showed moisture stress near the end of the growing season at each location. Camelina was also tested and was found to be well adapted to our region. However, at that time, there was little industrial interest in camelina seed as a source of oil. Beutler suggested that the crop may become useful if industrial traits could be improved by breeding and selection.

Vance Pumphrey continued to evaluate the agronomics of rapeseed production during the early and mid-1980s. That set the stage for large-scale screening of multiple types of crops in the Brassicaceae family at both Moro and Pendleton during the late 1980s, under the leadership of Drs. Don Wysocki and Jack Brown, a Brassica species breeder at the University of Idaho. Wysocki and Brown screened hundreds of spring- and fall-planted lines of canola, mustard and camelina. That research continues at the present time. More importantly, Wysocki and Brown also conducted intensive studies on all aspects of the production systems for these crops, including planting dates, planting rates and depths, row-width spacings, fertilizer placement, insect and disease control practices, and techniques that could minimize the loss of seed during harvest.


Vance Pumphrey and Mathias Kolding

In 2008, Dr. Donald Wysocki reported results of more recent tests with camelina. It was more tolerant of drought and cold than other oilseed crops, and was a short-season crop that could be harvested either directly or by swathing. Experiments with 12 lines provided by a cooperator in Montana were conducted to examine seeding rates, nitrogen fertilizer rates, and varietal performance at the Pendleton and Sherman Stations. Seeding rates did not affect productivity. The nitrogen fertilizer requirement appeared to be less than that of spring wheat. Crop yields varied from 1,000 to 1,400 pounds/acre at Pendleton and from 1,500 to 2,300 pounds/acre at Moro. Stands were affected by Rhizoctonia root rot.

Additional research on oilseed crops, particularly by Drs. Daniel Long, Catherine Reardon, and John Williams, examined the potential of modern Brassica crops and varieties for their agronomic performance and efficiency for serving as a renewable source of aviation jet fuel (Gesch et al., 2015; Gesch et al., 2019). To provide a comprehensive assessment of the various Brassica crops, the local


Dr. Donald Wysocki

scientists participated in a 7-state project to evaluate the species and varieties that performed best in a wide range of environments, from Iowa to Oregon. They also monitored an indicator of plant stress, to estimate relative drought tolerances of the various crops. Over a period of four years, these scientists evaluated in replicated plots, 12 varieties of six oilseed species, including *Brassica napus*, *B. carinata*, *B. juncea*, *B. rapa*, *Sinapsis alba* and *Camelina sativa*. Seed and oilseed yields generally increased with increasing growing season precipitation. Camelina was determined to have greater drought tolerance than the other crops. However, the scientists concluded that the seed oil content of some of the highest yielding varieties need to be increased before they will become viable as a biofuel feedstock.

USDA-ARS scientists at Pendleton and Pullman recently evaluated the influence of Brassica crops on water infiltration and microbial composition of soil. The main objective of that research was to determine if alterations to the microflora during the production of an oilseed crop will have a beneficial influence on the health of the following wheat crop.

Other Crops

Many other crops have been tested in replicated field nurseries since the inceptions of the Sherman and Pendleton stations. These crops included sorghum, coriander, castor bean, Russian sunflower, Russian dandelion for rubber, guayule, alfalfa for seed, anise, fennel, hemp and caraway. During the 1940s, the stations participated in a nation-wide search for areas that may be favorable for producing seed of rubber-producing plants (Russian dandelion and guayule) that were processed to produce rubber. The rubber-producing plants didn't prove satisfactory at Moro; dandelions produced low yields and the guayule plants all died during the winter of 1943 when the temperature in January dipped to -14°F. The work with Russian dandelion was continued through 1945.

The Sherman Station Annual Report for 1970 included 10 pages of data compiled from the fourth consecutive year of trials conducted with field and specialty crops grown in an off-station irrigation and fertilizer-testing program in the Klondike area of Sherman County. Similar irrigated testing was done 20 miles south of Arlington, in the Shuttler Flat area of Gilliam County. The crops tested under irrigated conditions included multiple varieties of potato, sweet corn, field corn, sugar beet, table beet, green pea, tomato, sweet potato, squash, watermelon, cucumber, cabbage, carrot, onion, parsley, barley, dry bean, green bean, lima bean, soybean, lentil, safflower, sudangrass, grain sorghum, crambe, sunflower, spring rape, and peppermint. Jack McDermid published a separate report each year to summarize the findings from those irrigation and fertilizers tests.

Scientists also examined potential alternative crops under irrigated and dryland conditions at the Pendleton Station and off-station locations. During the early 1960s, Laurn Beutler conducted a great many experiments to test varieties of flax, safflower, castor bean, sunflower, mustard, rapeseed, crambe, cape marigold, canary grass, proso millet, camelina, canaigre, dry bean, lentil, sesame, alfalfa for seed, and alfalfa for forage under dryland and irrigated conditions. Beutler's trials were conducted at locations as diverse as the Crow Pilot Farm near Weston (18 inches), Rew Farm west of Pendleton (11 inches), Storie Farm on the South Reservation (18 inch), and two locations in Wasco County where the rainfall was 10-12 inches without irrigation (Chastian Farm) or with a single irrigation (Peetz Brothers Farm).

Beutler also tested 20 alfalfa varieties for seed and for forage production. That work was done on an irrigated field near Umapine, where the alfalfa seed production industry is still located today. He also conducted continuous close grazing studies under dryland conditions to evaluate long-term survival of the alfalfa varieties over a five-year period. The same study was conducted at the Pendleton Station with six of the alfalfa varieties. Another selection of six varieties for forage production were tested at the Hermiston Station for four years. Also at Hermiston, Beutler tested 10 newer commercial varieties of alfalfa and planted 30 breeding lines for Dr. Rod Frakes, an alfalfa breeder at Oregon State University, at Corvallis.

During the late 1960s, Roland Schwanke tested pea, dry bean, baby lima bean, safflower, forage sorghum, grain sorghum, sugar beet, potato and onion at the Pendleton Station and at the Davis Farm near Adams. In the early 1970s, Vance Pumphrey conducted tests near the Crow Pilot Farm, at Weston, to examine pea, potato, onion, dry bean, bush bean, adzuki bean, mustard, rapeseed, soybean, safflower, field corn, grain sorghum, sunflower, carrot, and seed crops of leaf lettuce and radish. During the 1980s, Pumphrey again tested peas, lentils, chickpea, and faba bean over a 2-year period.

In the 2000s, Machado tested chickpea and many additional crops and published a review article to examine the potential for various crops to be integrated into the wheat-fallow system. Machado et al. (2016) described the climate of the area and why it dominated the selection of potential new crops. The report discussed adaptation and marketing potential of cool-season legumes (chickpea, faba bean, field pea, grass pea, lentil and lupin), warm-season grain legumes (soybean, peanut, common bean, mung bean and cowpea), oilseeds (rapeseed, mustard, safflower and sunflower), cereals (durum wheat, spelt wheat, einkorn, emmer, kamut, triticale, barley, oats, rye, buckwheat and grain sorghum), and crops with pharmaceutical and industrial uses (meadowfoam, flax, crambe, fenaf, lequerella, cuphea, euphorbia, vernonia, grindelia, hesperaloe, and sunn hemp).

In 2010, Dr. Donald Wysocki reported extensive testing of camelina varieties and in 2010, Drs. Steve Petrie and Stephen Machado reported recent tests of eight crops tested over a 3-year period at the Pendleton and Sherman Stations, including safflower, sunflower, yellow mustard, lupin, millet, buckwheat, linola and flax. Starting in 2019, Dr. Wysocki has collaborated with Oregon State University scientists at Corvallis to conduct tests of industrial hemp varieties. Optimal production environments and management systems will be identified.

Potato was a crop of strong interest during the first four decades of research at the Sherman Station. In 1911, the Station conducted a date-of-planting trial, depth-of-planting trial, and a row-spacing test for potato. The Station report for 1911 stated that "*The importance of the potato crop cannot be over-estimated. The average yield per acre for all varieties this year was 43.8 bushels, ranging from 9.7 to 81 bushels per acre, and placing this crop far in advance of any other grown, when considered from point of profit*." The potato trials continued until 1948 and involved the testing of many different varieties under many different agronomic production practices. The 17 potato varieties grown at Moro in 1915 were the first to be subjected to cooking tests by the Home Economics and Farm Crops Departments at Corvallis. Each variety was cooked four ways and then scored for mealiness, flavor, color and texture. "*The Burbank and Russet Burbank varieties were best.*" When tests of potato varieties were terminated in 1944, it was reported that potato had been screened at the Sherman Station every year since 1911. However, planting of potato as part of the crop rotation experiment continued until 1948, after which potato was removed from the rotations. The Russet Burbank potato and its progeny are still the leading varieties produced but they are no longer grown on silt loam soils under dryland conditions because productivity is much greater when potato is grown on irrigated sands.

Potato varieties were again tested under irrigated conditions during a four-year period (1967-1970) 20-miles northeast of Wasco, OR, and over a two-year period (1968-1969) at the Sherman Station. Jack McDermid concluded that potato, canning pea, sugar beet, dry bean and sudan grass were each "*crops that would produce an economic return with a suitable market outlet*."

Potato was also the subject of extensive investigations near the Pendleton Station from 1969 until 1972. Variety trials were conducted each year on an irrigated field at the Davis Farm near Adams and on a rainfed field at the Crow Pilot Farm near Weston. Potato quality on the silt loam soils at those locations was determined to be inferior to potatoes produced on sandier soils near Hermiston, and the tubers in the silt loam soils were much more difficult to dig with mechanized harvesting equipment. Also, potato at the sites near Pendleton were affected by wireworm, Colorado potato beetle and aphids. By 1972, Vance Pumphrey concluded that "*Commercial potato production does not appear to be practical on the silt loam soils near the foothills of the Blue Mountains*." Furthermore, he stated that "*Few crops are under produced in the United States. Any new crop considered for production must meet the competition from the area where it is presently produced. New production must have a competitive advantage if it is successful in obtaining a share of the market*."

Corn was a component of the rotation experiments that were initiated when the Sherman Station was established. After four decades of testing, it was decided to eliminate all of the 11 rotations in which corn was a component. Those treatments were discontinued during 1952 because "*corn is not adapted to this dry land area* [due to] *low rainfall, lack of summer rains, cool night temperatures, and low yields of poor quality corn.*" During the 40 years of testing, the average corn yield was only about 10 bushels per acre, and the product was of poor quality.

Corn began being tested at the Pendleton Station during 1930. Tests included a replicated variety trial that was continued for about six years, even though the yields for the 10 varieties were low and the product was of poor quality. Corn was also an important component of a rotation experiment established in 1930. There were two replicates of 35 rotations, and all phases of each rotation occurred each year. Data for each phase were collected annually. The rotations were divided into six groups; land alternately cropped and fallowed, continuous cropping, 3-, 4- and 6-year rotations that include a year of fallow, and rotations in which one year of a green manure crop was included. Corn was a component of 13 rotations. The rotation experiment started in 1930 was terminated after the 1953 crop. Averaged over 23 years, productivity of winter wheat was increased 14 bushels per acre when it followed a pea or a corn crop but all of the green manure crops (pea, sweet clover, alfalfa and barley) did not increase wheat yields and were "*definitely uneconomical.*"

Replicated trials with corn varieties and different rates of nitrogen fertilizer were again tested during a 10-year period from 1954 to 1964 at the Pendleton Station and the Crow 'Pilot' Farm near Weston. It was determined that early varieties of field corn may be an acceptable feed crop at Pendleton but later maturing varieties were not adapted. None of the feed or sweet corn varieties were adapted to the higher rainfall climate near Weston.

Flax was among the first potential alternative crops evaluated at the Sherman Station. Subsequent studies demonstrated that the existing varieties were not well adapted to the environmental conditions in Sherman County. But flax became a crop for extensive investigations in Umatilla County from 1962 until 1969. Laurn Beutler planted regional flax variety nurseries at the Pendleton Station. The varieties in each nursery were provided by scientists in North Dakota. At five locations with varying rainfall, in Umatilla and Wasco counties, Beutler also compared flax varieties and examined cultural practices to optimize each variety's productivity, and the chemicals needed to control the primary weeds at each location. Beutler stated that flax was a particularly promising crop at the Pendleton Station, with respect to yield, quality, economic return, and distribution of labor compared to the winter wheat crops. He reported data from up to 21 varieties that had been collected over a five-year period. His trials in Umatilla County were conducted at the Crow Pilot Farm near Weston (18 inches), Rew Farm west of Pendleton (11 inches), and the Storie Farm on the South Reservation (18 inch). The two locations in Wasco County were at the Chastian Farm (12-inch rainfall) and the Peetz Brothers Farm (10-inch rainfall plus one irrigation). Much information was gained regarding optimum planting dates, and of herbicides that could control lambsquarter, Russian thistle, coast fiddleneck, and black nightshade in the flax trials. The winter flax nursery froze out at these locations during one year.

Organic Agricultural Systems

Organic farming systems in areas of low-rainfall typically include the use cover crops, green manures, animal manures and crop rotations to fertilize the soil and promote biological activity. The goal is to maintain or improve the long-term health of the soil. Today, most farms that produce broad-acreage dryland crops do not include livestock operations to diversify the farm enterprise. An over-arching principle with organic agriculture is that the production system must be conducted without the use of synthetic pesticides and fertilizers. Weeds, insects and diseases are intended to be controlled by crop rotations, mechanical procedures and, where present, biological controls. The philosophy of organic farming includes recycling of nutrients, encouragement of natural predators to manage pests, increasing crop plant density to suppress growth of weeds, and other benign practices. Organic producers and advocates often claim that organic farming has fewer detrimental inputs into the environment, and produces a healthier product.

Much of the earliest research described in this and other chapters are directly pertinent to the concept of organic agriculture. This is particularly true for research before before herbicides, fertilizers and fungicides became widely used in dryland agriculture during the 1940s. Specific studies that are applicable to organic cropping practices include those on in-crop and fallow tillage practices, crop rotations, mechanical methods to control weeds, and cultural practices to suppress the severity of root diseases.

True organic cropping systems have also received specific attention from scientists during recent years. Dr. Daniel Ball tested applications of Brassica seed meals to determine if they could control weeds in spring wheat and peas. They didn't.

Dr. Stephen Machado conducted a five-level factorial experiment to examine methods for producing organic wheat at the Pendleton Station. The 10-year study, from 2005 until 2015, included three replicates of five treatments:

1. Two 2-year cropping systems; either a cover crop or an intercrop (crops planted together but harvested separately)
2. Two phases of each cropping system; planted or fallow
3. Two spring wheat cultivars
4. Two types of legume mixtures; clovers or medics
5. Four nitrogen application rates using an organic 4-4-4 fertilizer; rates of 0, 12, 24 or 28 pound N/acre/year

The cover crop options included spring wheat alternated with a mixture of either nine dryland clover species or six dryland medic species. The intercrop options included spring wheat planted simultaneously with either the clover of the medic mixture. The cover crop and intercrop systems were each a 2-year rotation with a planted and a fallow phase each year. Both systems were cultivated between crops using a sweep cultivator. As time passed, the experiment became progressively more contaminated with high densities of weeds. By 2013, there were uniformly high densities of fiddleneck tarweed and lower densities of prickly lettuce and Russian thistle. In 2015, the experiment was heavily and uniformly infested with common lambsquarters and with lower densities of prickly lettuce and Russian thistle.

In 2007, Machado conducted an experiment in the greenhouse to identify plants that secreted allelopathic compounds that are inhibitory to germination of downy brome seeds. He examined extracts from meadowfoam, radish, yard-long bean, blue spruce and pine. Each of those plants were found to produce compounds that inhibited downy brome but they also inhibited germination of wheat. Machado concluded that these plants have potential for suppressing downy brome in organic cropping systems.

In 2012, Machado initiated greenhouse and field studies to determine effects of applying biochar on growth of winter wheat. Biochar is a charcoal-like material produced by heating wood or other organic resources in an oxygen-limited environment. Chemical and physical properties of various biochars vary depending on the feedstock and combination of temperature and oxygen concentration during processing. The biochar studied by Machado had a pH of 10.6 and a C:N ratio of 500:1. It contained 90 percent carbon and less than 2 percent nitrogen. Biochar was applied at rates of 0, 10, 20 and 40 tons/acre. The soil had an initial pH of 4.8. In the greenhouse test, half the pots were also fertilized. Application of the 10 ton/acre rate in greenhouse pots led to an increase in wheat shoot and root growth. Higher rates of application did not lead to additional increases in plant growth in fertilized soil, and plant growth was suppressed by the 40 ton rate in unfertilized soil (Bista et al., 2019). Soil pH was increased in proportion to the amount of biochar applied, with an increase of about 0.5 and 1.2 pH units at the 10 and 40 ton/acre rates. respectively. In a field test, application of biochar at 10 tons/acre increased soil pH by 0.2 unit and increased wheat yield by 12 bushels/acre, from 45 bushels/acre to 57 bushels/acre (Yorgey et al., 2017). Since production and transport of biochar are expensive processes, interest in this technology is likely higher among organic than other farmers, and all farmers are unlikely to be interested in applying more than 10 tons/acre.

***References*:**

Annual Reports from the Sherman and Pendleton Stations (Appendices 5 and 6)

Letters sent to or from the Station Superintendents

Bista, P., R. Ghimire, S. Machado, and L. Pritchett. 2019. Biochar effects on soil properties and wheat biomass vary with fertility management. Agronomy 9:623. (online at doi:10.3390/agronomy9100623).

Corp, M., S. Machado, D. Ball, R. Smiley, S. Petrie, M. Siemens, and S. Guy. 2004. Chickpea Production Guide. Oregon State University Extension Publication EM8791-E. 14 pages.

Gesch, R., T. Isbell, B. Allen, D. Archer, J. Brown, J. Hatfield, J. Kiniry, D. Long, and M. Vigil. 2015. Comparison of several *Brassica* species in the northcentral U.S. for potential jet fuel feedstock. Industrial Crops and Products 75:2-7.

Gesch, R. W., D. S. Long, D. Palmquist, B. L. Allen, D. W. Archer, J. Brown, J. B. Davis, J. L. Hatfield, J. D. Jabro, J. R. Kiniry, M. F. Vigil, E. A. Oblath, and T. A. Isbell. 2019. Agronomic performance of Brassicaceae oilseeds in multiple environments across the western USA. Bioenergy Research. 12:509-523.

Machado, S., B. Tuck, S. Macnab, J. Maley, and J. Igo. 2016. Alternative crops for the Columbia Basin. Oregon State University Extension Service Bulletin 8915. 32 pages.

Yorgey, G., W. Pan, R. Awale, S. Machado, and A. Bary. 2017. Soil amendments. Pages 283-318. In: Advances in Dryland Farming in the Inland Pacific Northwest (G. Yorgey and C. Kruger, editors). Washington State Universtiy, Pullman, WA. 614 pages.

Partial List of Crops Studied at the Sherman and Pendleton Stations

Small Grain Crops

spring barley
winter barley
spring oats
winter oats
durum wheat
einkorn wheat
emmer wheat
spring wheat
winter wheat
spelt wheat
buckwheat
teff

Oilseed Crops

castor bean
flax
linola
sunflower
safflower
crambe
camelina
cape marigold
meadowfoam
soybean
spring canola
winter canola
spring mustard
winter mustard (rapeseed)
yellow mustard

Dryland Greens Crops

sugar & table beet
swiss chard

Legume Seed Crops

alfalfa
crimson clover
subterranean clover

Vegetable Seed Crops

carrot
lettuce
radish

Grass Seed Crops

wheat grasses
orchard grass
brome grasses
fescue grasses
canary grass
blue grasses

Feed Crops

field corn
cereal rye
proso millet
grain sorghum
triticale
blue lupin (narrow-leaf)
white & yellow lupin
Austrian winter pea

Forage Crops

alfalfa for forage
alfalfa for hay
barrel medic
sudan grass
forage sorghum
guar
Columbus grass
sweet clover
wheat grasses
wheat grasses + alfalfa
fescue grasses
fescue grasses + alfalfa
13 other grass species
Austrian winter pea
hairy vetch
sunn hemp

Vegetable Crops

adzuki bean
bush bean
dry bean
faba bean
green bean
lima bean
navy bean
pinto bean
snap bean
string bean
table beet
mung bean
cabbage
carrot
chickpea
sweet corn
cowpea
cucumber
kale
lentil
onion
parsley
dry & green pea
sweet potato
sugar pumpkin
radish
acorn squash
yellow-neck squash
tomato
turnip
watermelon

Root Crops

sugar beet
potato
canaigre
peanut

Rubber Crops

Russian dandelion
guayule

Other Crops

anise
caraway
coriander
cuphea
euphorbia
fenaf
fennel
grindelia
hemp
hesperaloe
kamut
lequerella
peppermint
sesame
vernonia

Chapter 10 - Rangeland

Range and pasture forages were among the first crops to be planted when the dryland experiment stations were established at Moro and Pendleton. The primary goal of early studies was to evaluate the productivity of different grasses and legumes, and to determine how long and how well they maintained their stands without intervention. Later studies evaluated the efficiency of methods for maintaining or improving rangeland, and of methods to convert rangeland into wheat production. The latter topic became particularly pertinent during the recent years when rangeland planted one or more decades earlier, as a component of the USDA Conservation Reserve Program, was again being converted for the production of wheat.

Most experiments with range grasses and legumes were conducted to evaluate their productivity. Results of those studies were published mostly by the USDA-SCS (Hafenrichter et al., 1968; McClure et al., 1958; Rampton, 1957; Schwendiman, 1976), and were summarized in Chapter 8.

Establishment

Most research on rangeland establishment was conducted at experiment stations at Burns and Union, and in other states. Only a few experiments at Moro and Pendleton were specifically designed to evaluate methods to establish rangelands most efficiently.

The first Superintendent, Harry Umberger, initiated a date-of-planting study with alfalfa during 1910. Dr. Daniel Ball also conducted a small number of experiments on establilshment of rangeland, with a goal of evaluating ways to control annual grasses in range. Ball also planted range grasses without seedbed tillage to evaluate the ability of improved grasses to compete with invasive grasses such as downy brome. He used a Truax Roughrider No-till Rangeland Drill for that purpose. Ball modified a truck to pull the heavy rangeland drill and its custom trailer to sites as far as Wallowa County. The research was conducted but results do not appear to have been reported.

In his 2008 Annual Report of Weed Science research, Dr. Ball reported that he established range experiments east of Pilot Rock. He applied different herbicides to suppress medusahead rye and downy brome in established rangeland, and then planted four species of native grasses without tillage into individual replicated 15 × 40 foot plots. The grasses were bluebunch wheatgrass, sandberg bluegrass, squirreltail bottle brush and Idaho fescue.

Maintenance and Improvement

Only a few studies were conducted on the maintenance or improvement of rangelands. In 1962, Dr. Arnold Appleby evaluated various herbicides for their ability to suppress or control diffuse knapweed that had encroached into rangelands. In 2009, Dr. Daniel Ball evaluated applications of herbicides to suppress growth of invasive weeds in a native grass seed-production farm at Connell, WA. Many herbicides or combinations were evaluated on various native grass stands. Ball also established a similar study to determine the tolerances to four herbicides of nine species of range grasses planted at the Hermiston Station. There do not appear to be any reports of fertilizer or other agronomic research for managing or improving rangelands.

Converting Rangeland to Crop Production

In the 1940 Annual Report from the Sherman Station, Merrill Oveson stated that about 150,000 acres of wheat land in eastern Oregon was growing grass as a soil building crop under the Agricultural Adjustment Act (AAA). The AAA was a component of the New Deal program that sought to raise crop prices by lowering production, which the government achieved by paying farmers to leave a certain amount of their land unseeded. Oveson predicted that when payments under the AAA program were terminated, most of that land would be reseeded to wheat. Oveson emphasized the need for more research to find the best methods that would allow those transitions to be economically feasible. Oveson began that transitional research immediately.

In 1940, Oveson cultivated selected 5- to 7-year old forage stands that had been initially established to evaluate the productivity of grasses and legumes, as discussed previously. The old forage ground was then maintained either as a winter wheat-cultivated fallow or spring wheat-cultivated fallow rotation. Comparative measurements were made of wheat yield and soil quality in each successive wheat crop. In

1944, the winter wheat yields were progressively lower after increasing numbers of years in rangeland; 24.0, 22.0, and 19.9 bushels/acre following long-term winter wheat-summer fallow, winter wheat after five years of wheatgrass, and winter wheat after seven years of wheatgrass, respectively. In 1951, the average yield for six winter wheat crops was 29.5, 30.1, 29.1 and 29.9 bushels/acre after taking out 5-year-old stands of alfalfa, crested wheatgrass, a mixture of the two pasture species, or production of wheat in a wheat-fallow rotation. For production of spring wheat after a year of fallow, the yield for those treatments was 25.2, 27.9, 25.9 and 26.0 bushels/acre. The only important differences in the averages came from very low yields during the first wheat crop in the two treatments that contained alfalfa. High nitrogen concentrations in the old alfalfa soil caused the plants to grow luxuriously and to prematurely deplete the soil of water. At the same time there was a low rainfall, which caused a crop failure that first year, with winter wheat yields of 2 to 6 bushels/acre for the first crops of spring wheat and winter wheat, respectively, in treatments following alfalfa. After the first year, yields were comparable in all treatments.

In another experiment with conversion of forage land to wheat, the experiment at Moro had gone through its sixth wheat-fallow cropping season in 1958, at which time the average wheat yield following five years of alfalfa, wheatgrass, or the mixture of these species, exceeded those of the wheat-fallow rotation, with little difference among the three pasture-takeout treatments. After the first season, the highest yields were consistently collected from the two treatments that included alfalfa. This trend following 5-years of alfalfa continued through the eighth consecutive crop of winter wheat in a wheat-fallow rotation following the conversion of perennial alfalfa to a winter wheat-cultivated fallow rotation.

A new wave of rangeland conversion to wheat production began in the 2000s as lands formerly planted to grasses and forbs, as part of the USDA-Conservation Reserve Program, were completing one or more cycles of 10-year contracts. Renewed questions arose about the most efficient manner to achieve that conversion. Dr. Daniel Ball established a multi-year experiment on a 15-year-old rangeland at the Sherman Station to determine the best combinations of herbicide application and tillage to kill old grasses and to break up the clumps of bunchgrass roots and stems to prepare an acceptable seedbed. Results of that research do not appear to have been reported.

Dr. Richard Smiley evaluated populations of fungal pathogens that were affecting first- and second-year crops of wheat and barley after CRP grasslands were taken out near Dayton, WA. He reported that Rhizoctonia root rot was especially damaging in those early wheat and barley crops. In 2006, Smiley evaluated the density of root-lesion nematodes in two varieties of first-year spring wheat that had been planted into different halves of a former CRP field east of Heppner, WA. The field had been planted to a mixture of intermediate wheatgrass, sheep fescue and Siberian wheatgrass in 1988, and was cultivated and planted to spring wheat in 2006. While the nematodes were detectable in the former grassland, they were found to occur at densities about half as high as in nearby fields that had been cropped repeatedly to wheat or canola. Smiley then evaluated the ability of two common species of root-lesion nematode to survive and multiply on 18 species of range plants and 16 species of weeds under controlled conditions in the greenhouse. For range grasses, he reported that plants that were good hosts for both nematode species included 'Critana' thickspike bluegrass, 'Manchar' smooth brome, and seven wheatgrasses (Smiley et al., 2014). Good hosts for the nematode species *Pratylenchus neglectus* but not for *P. thornei* included two hairy vetches, 'Rosana' western wheatgrass, 'Sherman' big bluegrass and 'Alkar' tall wheatgrass. In contrast, range plants that were good hosts for *P. thornei* but not *P. neglectus* included 'Durar' hard fescue and 'Blacksheep' sheep fescue. Neither of the nematode species multiplied efficiently on two species of alfalfa. Since crop plants and weeds exhibited similar variability in their hosting abilities for these two nematode species, it became clear that it was important to determine the identity of any root-lesion nematode detected in range land and to match that information with the sensitivity of the intended first or second crop that is to be planted after range in converted back to crop production.

References:

Annual Reports from the Sherman and Pendleton Stations (Appendices 5 and 6)

Letters sent to or from the Station Superintendents

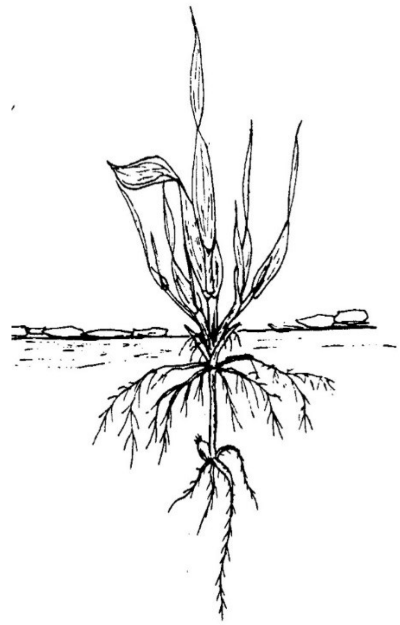
Hafenrichter, A. L., J. L. Schwendiman, H. L. Harris, R. S. MacLauchlan, and H. W. Miller. 1968. Grasses and Legumes for Soil Conservation in the Pacific Northwest and Great Basin States. Agriculture Handbook 339. USDA Soil Conservation Service, Washington, D.C. 69 pages.

McClure, N. R., A. L. Hafenrichter, and J. L. Schwendiman. 1958. Grasses and Legumes for Conservation Farming in North Central Oregon and Adjacent Areas. USDA, Soil Conservation Service M-2188, Portland, Oregon. 41 pages.

Rampton, H. H. 1957. Forage, Seed, and Specialty Crop Variety Recommendations for Oregon. Oregon Agricultural Experiment Station Circular of Information 577. 28 pages.

Schwendiman, J. L. 1976. Grasses and Legumes for Conservation Use in Semiarid Wheat-Fallow Areas of Eastern Oregon. USDA Soil Conservation Service, Portland, Oregon. 102 pages.

Smiley, R. W., G. P. Yan, and J. A. Gourlie. 2014b. Selected Pacific Northwest rangeland and weed plants as hosts of *Pratylenchus neglectus* and *P. thornei*. Plant Disease 98:1333-1340.



Chapter 11 - Trees, Shrubs and Flowers

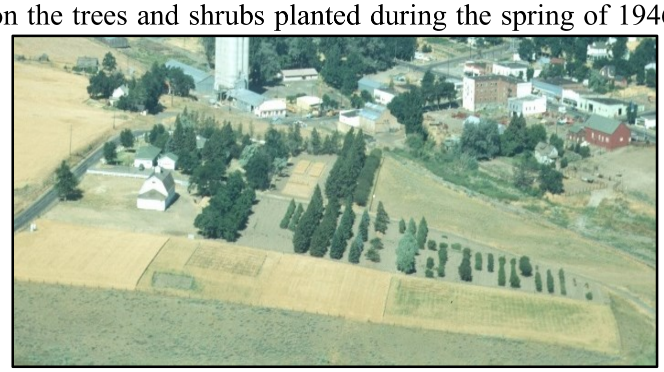
Early farmers in all dryland areas had a strong interest in improving the appearance of their homes as well as to provide shelter from the wind. There was uncertainty as to which tree and shrub species were adapted to the climate of each region. This was especially true when the Sherman Station was being established in 1910, particularly since the most likely sources of trees and shrubs were in the high-rainfall and milder climate areas west of the Cascade Mountains. By the time the Pendleton Station was established in 1928, the uncertainty about adaptation of plants continued but commercial nurseries were already present in northern Umatilla County.

Sherman Station

Within two years after the Sherman Station was established, the Forest Service Department of the USDA supplied 11 varieties of trees for planting and testing at the Sherman Station. After being planted in 1912, the station staff started recording notes on the establishment and vigor of each species. Many more ornamental tree species were planted during 1913, and an even larger selection of fruit and shade trees were planted during 1923 and 1924. In communications between Dave Stephens and M. S. Brown, Chief in Horticulture, Oregon Agricultural College, it was clear that Stephens had planted hundreds of fruit trees, shade trees, grapes, shrubs, vines and ornamentals at the Sherman Station. These were in addition to the many plantings made previously. He outlined exquisite details for the spacing and spatial arrangement of each of the varietal entries within each row, and the locations of those rows. In 1927, Stephens prepared a checklist of the survival, growth and vigor for 343 specimens that included apple, crab apple, pear, peach, apricot, cherry, plum, choke cherry, currant, gooseberry, raspberry, black berry, grape, oak, walnut, honey locust, mountain ash, sugar maple, white elm, white ash, green ash, burr oak, hawthorn, firebush, honey suckle, mock orange, golden ninebark, tartarian maple and Himalayan lilac.

USDA-Soil Conservation Service tree nursery at Moro; planted in 1913, photo in 1927

The USDA-SCS provided guidance and assistance with additional large plantings of trees and shrubs at the Sherman Station from 1946 to 1948. Plantings during 1946 included 100 deciduous trees, 100 evergreen trees, 75 deciduous shrubs, 25 evergreen shrubs, and 100 short erect shrubs. During the next two years, 275 more plants in other genera and species of these groups were planted. The 1947 Sherman Station Annual Report included tables of information on the trees and shrubs planted during the spring of 1946, with notes on plant survival, height, spread, conservation ratings and pruning needs. Data on the 1946 plantings were taken at 5-year intervals to record survival, height and spread. For the third such documentation, the 1958 Sherman Station Annual Report included charts of growth rates for each tree species. The station demonstrated that Russian Olive, Caragana, and Western Yellow Pine could be successfully grown for shade and windbreak purposes in low rainfall areas in eastern Oregon. Oveson (1940) reported that "*In recent years numerous bleak, windswept farmsteads have been planted to these trees*."



USDA-Soil Conservation Service tree and shrub nursery at Moro (1970)

In 1961, the effect of drought and competition of trees and shrubs with grasses between rows of the woody plants could be seen on some of the tree and shrub species in the nursery, particularly the Scotch Pines. This was thought to have been complicated by the planting of bulbous bluegrass between rows of trees several years earlier for the purpose of eliminating the need for tillage between tree rows. Granular

Simazine was therefore applied under the trees to eliminate competition from grasses and weeds. All trees and shrubs were evaluated and measured during 1962 by Robert Olson, a Woody Plant Specialist with the USDA-SCS at Pullman. It was noted that some of the tree species had attained their maximum mature plant height. Findings from data collected at Moro and other locations in the western U.S. were published in several USDA bulletins. In Oregon, observations of the best or worst species for use in windbreaks were presented by Ross (1972).

By 1996, many of the trees at the Sherman Station had become severely affected by diseases (Armillaria root rot and blue mold) and insects (mountain pine beetle and locust borer) that commonly infest older trees that are already in a natural decline due to age. The 177 trees that were most damaged or killed by these pests were removed from the station, which terminated the nursery that had been established 50 years earlier.

An attempt was made in 1997 to establish another planting of ornamental shade trees to beautify the station grounds and provide a park-like setting for the citizens of Moro. The planting was named the Sherman Station Memorial Grove. Sherman County employees and equipment smoothed the land to facilitate mowing of grasses and weeds that would grow between the trees. An irrigation system designed and supplied by Wheatacres Irrigation was installed by station staff. Thirty-eight specimens of 14 species of deciduous and evergreen trees were purchased and planted. The trees were planted and labeled with a plaque that included the tree name and the person to whom it memorialized. Dedication of the grove occurred at the same time as the dedication of a newly-installed wall plaque which acknowledged those who had donated to the Sherman Station Endowment Fund. Most of the trees began to deteriorate within the first five years because they became stressed by too little water and too much wind, heat or cold. Trees that were still alive were removed in 2012 to prepare land for construction of a new office building.

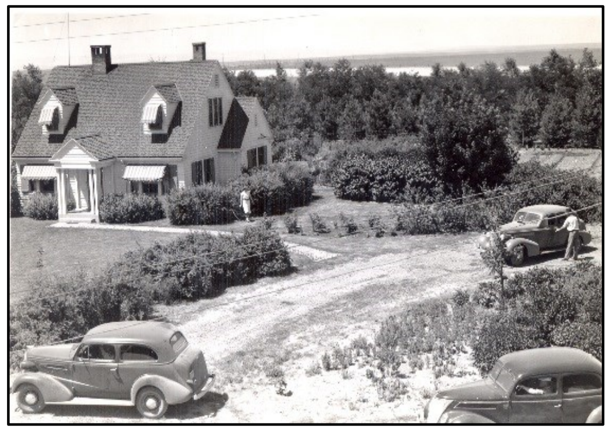
Tests of 42 chrysanthemum varieties were tested at the Sherman Station from 1954 to 1960 in an effort to provide guidance for home beautification in that dry climate. The old plants were divided and rooted each year, and five plants of each variety were planted in a row. The nursery was planted in front of the station house and "*received considerable attention from passers-by on the county road. Many visitors stopped to view the planting*." The station staff took notes each year to record flower color, flower type, dates of bloom (first, full and last), total days of bloom, conditions of bloom after a sub-lethal frost and after the first killing frost. Remarks regarding the best uses of the variety were also recorded. Detailed data from this chrysanthemum trial were reported in the Sherman Station Annual Reports (see Appendix 5) and in an unpublished 6-page report by Bill Hall in 1957. The chrysanthemum trial was terminated abruptly in 1960, after the parent plants all died after being transplanted.

Pendleton Station

Plantings of trees, shrubs and flowering plants at the Sherman Station were surprisingly large, complex and well-integrated into the research and aesthetic functions of that station. Amazingly, the horticultural plantings at the Pendleton Station surpassed those at the Sherman Station. Plantings at Pendleton were included in the plans for buildings and grounds. On November 28, 1928, initial architectural drawings for the Pendleton Station, prepared by the architect at the Oregon State Agricultural College, showed the future locations of the dwelling house, garage, machine shed, bunkhouse, barn, barnyard, vegetable garden and flower garden.

David Stephens sent a letter dated March 11, 1930 to the Dean of the Forestry Department at Oregon Agricultural College. "*I wish you would ship to George A. Mitchell, Pendleton Field Station, Pendleton, Oregon, the following trees: 50 western yellow pine, 50 Scotch pine, 150 Austrian pine, 100 Douglas fir, 50 Chinese elm, 200 black locust, 100 box elder. I understand that you do not have any Caragana or Russian olive trees. We shall get some of these from Mandan, North Dakota, if possible. I wish you would also send to me, addressed to Moro, about 100 Chinese elm, if you can spare that many.*" One day later, Stephens sent another letter to his brother, John Stephens, at the USDA Office of Dry Land Agriculture, in Washington, D.C., stating "*We are planning to plant a lot of trees on the Pendleton Station this spring, and there are a few varieties which we are unable to get from the Forestry Department here. I wonder if we could get about 50 each of the following varieties from one of your Great Plains field stations; Caragana, Russian olive and Black Hill spruce. I am having sent to Pendleton 700 Western yellow pine, Scotch pine, Austrian pine, black locust, Chinese elm and box elder. If you have any new introductions that you think would be adapted to the Pendleton country we should be glad to have you include some of them in the shipment with the other trees. I would write directly to Mandan but I do not know who is in charge there* *during your absence*." John Stephens was at that time the Superintendent of the USDA branch experiment station at Mandan, ND.

On April 8, 1930, George Mitchell also purchased two trees (weeping birch and poplar), seven lilacs, and 36 shrubs (of seven different varieties) from the Milton Nursery in Milton, Oregon. About a month later, Mitchell submitted the invoice for that purchase. In his letter to the OAES, dated April 15, 1930, he stated "*I am inclosing requisition for trees and shrubs used in landscaping the Pendleton Field Station grounds. Mr. Stephens told me to go ahead and purchase the shrubs from the Milton Nursery as the season for planting was so far advanced by the time the plan arrived from Prof. Peck. ... All the trees and shrubs have started growth. ... I hope you will be able to make an official inspection trip soon. Everything is in ship shape. Our plowing has been completed, the roadways seeded, the plats all trimmed, and most of the weeds cleaned up. In a couple of years we will have a wonderful place, and one to be really proud of*." Mitchell's letter and invoice prompted a rebuke from James Jardine, Director of the OAES. Jardine sent a letter a letter to Mitchell stating "*Your requisition and claim for shrubs for your station just came in. I hope that in the future you will be able to get the approval of the State Board of Control before making purchase. ... Your State Appropriations are getting low. I hope it will be possible for you to keep your expenditures within your available funds. ... I hope to see Stephens by the end of this week and we can get some of these matters straightened out.*" Mitchell didn't respond, which prompted Jardine to send four more letters to Mitchell over the next four months; May 5 and 22, June 21 and August 20. Those letters each demanded that Mitchell submit proper justification for his "*immediate need for purchase of the shrubs*." After he had completed the winter wheat harvest, Mitchell finally submitted a full-page explanation. He explained why he felt compelled to make the ornamental purchases without first receiving an authorization for a purchase order from the State Board of Control. It sounded pretty convincing! But the real reason for the Station Director's insistence on this matter probably related more to the fact that in that same bundle of letters, there were many others with the same complaint; Mitchell apparently had a penchant for purchasing goods without authorization and then submitting the bills for payment without explanation, setting off a flurry of sharply worded letters back and forth between Mitchell, Jardine, and suppliers who weren't getting paid in a timely manner by the business offices at Corvallis and in Washington, D.C. An undated letter in that same file of letters, written by Mitchell to the Oregon Agricultural College Business Office, also stated why he had an urgent necessity to purchase a 17-inch, 5-blade lawn mower. Mitchell concluded that letter by stating "*I have worn the neighbors mower out*."



Ornamental plantings at Pendleton (1939)

Those communications during the spring and summer of 1930 did not slow the flow of orders for trees, shrubs and ornamentals for the Pendleton Station. On October 16, 1930, Mitchell sent a letter to the Business Office at Oregon State Agricultural College. The letter stated "*We are enclosing the following warrants ...*" for payment of bills that totaled $567.43. One was for $232.93 to the Milton Nursery Co. Mitchell had obviously planted more trees, shrubs and lawn at the Pendleton Station. And so it continued!

Ornamental plantings at Pendleton (1950)

Mitchell sent a letter to Prof. A. L. Peck, Landscape Gardening Department at Oregon State College, Corvallis. The letter dated February 5, 1931, stated "*I am sending under separate cover a copy of the landscaping plans for the Pendleton Field Station. I would like very much to secure your help in planning a perennial border between the* *lawn and shrubs in the rear of the house. … I would like to have a border which would produce flowers for a long period from early spring until late into the fall or winter. … I am including a list and numbers of the perennials we have at present. … I have a cold frame and plan to start a large number of perennials in this frame.*”

In yet another round of beautification of the station grounds, Ralph Besse, Vice Director of the OAES, sent a letter to Mitchell on July 16, 1935. The letter stated, in part, “*Subject: Proposed Ornamental Planting Project.*” “*We have engaged Fred Cuthbert of the School of Fine Arts, Department of Landscape Architecture, to visit your Station some time in the near future to discuss with you the possibility and feasibility of establishing an experimental project with ornamental plantings. Mr. Cuthbert …. will be able to outline a detailed plan for conducting such an experiment. We want you to feel perfectly free … to indicate your personal desires and wishes. … Mr. Cuthbert can be of material assistance, and is being sent to your Station for that purpose*.”

While the above-named purchases of trees and shrubs may seem overwhelming for a rural branch experiment station, that emphasis on horticultural plantings cannot be fully realized without listing of at least some of the purchases or ornamentals made by the Pendleton Station during its first decade of existence. The following list shows examples of some of the orders that were placed and the nursery location from which they were purchased. All of these ornamentals were purchased using funds from the Oregon State Board of Higher Education. Guidance for some of the selections was provided by W. S. Brown, Chief, Department of Horticulture, Oregon State Agricultural College, Corvallis. Brown made his suggestions based upon considerations of plant adaptation to summer heat, winter-hardiness and availability of water.

March 15, 1930, from Milton, OR: 455 trees and shrubs! Including black walnut, linden, poplar, horse chestnut, plane, birches, maples, crab apple, spirea, forsythia, lilac, hydrangea, roses, and others

March 30, 1930: from Corvallis: the Station paid railway express charges for 700 “trees from Corvallis, Oregon”

May 30, 1930, from Portland, OR: 10 pounds of Kentucky bluegrass seed and 8 pounds of white clover seed

March 16, 1934, from Milton: 1 hawthorne, 1 sycamore, 6 barberry, 12 sweet mock orange, 5 spirea, 18 quince, and 30 other varieties of small flowering bushes

March ?, 1934, from Milton: three 10-12 foot high trees, 2 maple and 1 sycamore

March ?, 1934, from Mandan, ND: 8 plum trees

March 16, 1934, from Bismarck, ND: 12 2-year-old roses and 14 dwarf flowering almond

March 16, 1934, from Philadelphia: six 2-year-old roses

August 8, 1934, from Milton: 10 youngberry, 10 raspberry, 6 blackberry and 6 grape

March 19, 1935, from Painesville OH: 25 plants flowering annual and creeping groundcover plants (5 varieties)

October 24, 1935, from Milton: 10 varieties of peony

January 11, 1936, from Philadelphia: 10 seed packets (calendula, larkspur, nasturtium, delphinium, heliotrope, and others

April 2, 1936, from Milton OR: 16 roses (4 varieties), 7 viburnum, 5 fosythia and 7 flowering almond

April 27, 1936, from Ontario CA: 10 roses (4 varieties)

March 9, 1937, from Milton: 15 forsythia, 5 weigela, 1 tulip tree, 1 Norway maple and 10 other flowering shrubs (*Duetzia lemoine*)

March 9, 1937, from Multnomah, OR: 16 barberry and 30 roses (8 varieties)

April 7, 1937, from Salem OR: 100 caraganna, 100 Russian olive and 100 western yellow pine

April 10, 1937, from Faribault, MN: 10 lilac (2 varieties)

February 2, 1938, from North Abington, MA: 3 rose bushes

February 21, 1938, from Rutherford, NJ: 3 rose bushes

February 21, 1938, from Philadelphia: seed of five aster varieties, snapdragon, lupin, nasturtium, lobelia, and others

February 21, 1938, from Shenandoah, IA: 4 quince, 2 dogwood, 6 roses, viburnum and phlox

March 2, 1938, from Philadelphia: 19 roses (9 varieties)

March 9, 1938, from Shenandoah, IA: 24 carragana, 64 spirea, 1 flowering crab, 1 peach, 3 lilac, 8 sweet mock orange, 2 phlox and 29 roses

March 9, 1938, from Philadelphia: 3 roses, 4 asters, 6 chrysanthemums and 10 packets of seeds of zinnias, lupins, asters, larkspur and sweet William

April 5, 1938, from Portland: 15 pounds of Kentucky bluegrass seed and 4 pounds of white clover seed
April 14, 1938, from Philadelphia: 1 rose
October 3, 1938, from Philadelphia: 7 roses and 6 dozen tulips
March 31, 1939, from Beltsville, MD: 66 chrysanthemums (11 varieties)
March 28, 1939, from Shenandoah IA: 29 2-yr-old rose (14 varieties), 4 juniper, 3 daphne, 3 viburnum, 3 grape varieties, 205 gladioli (12 varieties), 14 delphinium (3 varieties) and 11 lilac (4 varieties)
March 6, 1940, from Pullman, WA: packets of seed for 18 different species of flowering legumes, including sweet peas, lupines, sainfoin, crimson clover, vetch, and some imported species. The packets were labeled "*Observational*" and were sent by Virgil B. Hawk, Manager, Outlying Nursery Unit, USDA-SCS. The cover letter stated "*Several days ago we sent you seed of legumes which I promised Mrs. Mitchell.*"
May 4, 1940, from Shenandoah, IA: 4 rose, 4 aster, 22 phlox and 100 strawberry

There were many, many more orders over the years but those shown above provide an insight into the vast number of ornamentals planted and maintained at the Pendleton Station. However, it is assumed by this writer that many of those plants must have died, providing space for additional plantings.

The Pendleton Station received many 'tourists' who came to the station solely to view the horticultural plantings. Gwendolyn Mitchell, the Superintendent's wife, even hosted 'field days' to guide groups through the gardens. The following entries relate to these horticultural activities at the Pendleton Station.

March 19, 1934; from a typed letter to George Mitchell from D. E. Richards, Superintendent, Experiment Station, Union, OR – "*Dear Friend: It has been called to our attention a number of times that you have some twelve million varieties of iris that all bloom at one time, making a most beautiful sight. Please write us whenever all of these are in bloom and we will slip over to see them*." Mitchell replied on April 24 - "*Our sixty varieties of iris will be in full bloom about next Sunday. We would like to have you and your family spend the day with us, we shall have dinner about one thirty*." Richards responded that they would still be shearing sheep on Saturday and Sunday, and would drive over to visit some afternoon during the week.

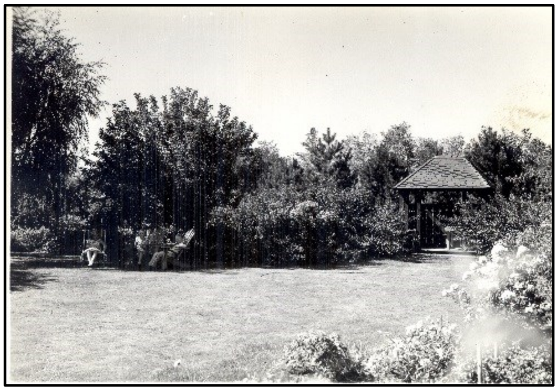
March 15, 1935; from a 1-page letter from George Mitchell to Mr. Tucker, of Spokane WA – "*When you visited our station recently you told me of the motion pictures that you have of you own prize winning garden and other interesting gardens in Spokane. You also stated that you would be willing to show your pictures before a group in Pendleton. I have been requested by members of the Pendleton Women's Club to ask you to come to Pendleton to show your pictures and give some of your gardening experiences and advice on the afternoon of March 21st. The club provided no funds in their budget for this expense, but if you can see your way clear to come I am sure that you will have an attentive and appreciative audience. The Mitchells will feel honored if they can entertain Mrs. Tucker and yourself as well as help cut some of your expense.*" … [Note: this was an exceedingly short, 6-day advance notice to request that Mr. Tucker drive to Pendleton from Spokane in 1935]

April 21, 1940; from a 1-page letter from Gwendolyn Mitchell, to the State Garden Clubs, Inc., 30 Rockefeller Plaza, New York City – "*Please send me a copy of your book Judging the Amateur Flower Show*." She sent payment for the book and for postage to send it by airmail.

June 25, 1941; from the Pendleton Rotary Club's weekly bulletin - "*Rotarians and their ladies held their annual Rotary picnic in the evening when Mr. and Mrs. George Mitchell were hosts in their beautiful gardens at the Pendleton Field Station. Tables were spread on the lawn, in a setting of trees and flowers, some 70 enjoying a delicious pot-luck supper, with special dishes prepared by Rotary Anns. Before supper Rotarians limbered up in a softball game. The evening closed with the showing of singularly lovely natural color motion pictures, by Harold Dobyns, district agent for the Federal Fish & Wild Life Service, the themes being his 172 mile boat trip down the Owyhee River and of predatory hunting of coyotes*."

The gardens at Pendleton were obviously an attractive feature on an otherwise semi-arid landscape. The shelter belt planted around the Superintendent's house was a functional feature that was completed during 1930. It included black locust, Douglas fir and ponderosa pine trees. The 1933 Pendleton Station Annual Report includes photographs of a well-established windbreak.

A series of communications during 1937 included a letter in which the OAES refused to grant permission for George Mitchell to purchase a Jacobsen power lawn mower. The complication was that Mitchell was already using that mower! In the letter of denial, dated June 9, Ralph Besse stated "*I am afraid that we would be criticized by the authorities from the President to the Board for the purchase of this type of equipment. Would it be possible to find an electric lawn mower that would cost less money which might be obtained with less criticism?*" Upon receiving the letter, Mitchell notified the Western Golf Course Supply Co., in Portland, that he had been denied permission and was very disappointed. Furthermore, Mitchell stated that "*I shall clean the mower up and take* [it back to] *the Taylor Hardware Co. tomorrow*." On June 14, Western Golf Supply responded to Mitchell, stating their surprise at the Experiment Station's decision. That letter included the statement "*The experimental station at Union purchased a larger size mower than yourself and we have also been assured of one for Burns*."



The Mitchell's relaxing in the back yard of their residence at the Pendleton Station during 1939

The Mitchell's also provided planting stock from the horticultural plantings at Pendleton. One such example was noted in a letter to George Mitchell from William A. Schoenfeld, Dean and Director, Oregon State Agricultural College and OAES. In a letter dated May 5, 1938, Schoenfeld stated "*The box of chrysanthemums arrived in good shape. Thank you very much for your thoughtfulness in sending them to me.*"

As already stated for the Sherman Station, personnel from the USDA-SCS Plant Introduction Station at Pullman took notes on tree and shrub survival, height, spread, conservation ratings and pruning needs. Pendleton Station personnel also collected notes on some of the flowering plants such as chrysanthemum, gladioli and iris. One of the scientific uses of the horticultural plantings was exemplified by the herbicide trials conducted by the Pendleton Station's Weed Scientist, Dean Swan, during the late 1950s. Swan conducted herbicide trials in the tree windbreak and in the iris and tulip beds that lined the driveway into the Pendleton Station. He demonstrated that an application of Simizine completely suppressed weeds such as cheatgrass without any apparent injury to either the iris or tulip plants.

During the 1980s, a lawn west of the original greenhouse was renovated and planted to 24 blocks of cool-season turfgrass species, varieties and mixtures of species. The grasses included Kentucky bluegrass, fine-leaf fescue, tall fescue and perennial ryegrass. Notes were taken on stand establishment and various quality traits. The turfgrass demonstration planting was lost in the early 1990s when that land was cleared to construct a new greenhouse and a wastewater drain field.

Horticultural plantings at the Pendleton Station are currently in a state of disarray. An older section of the shelterbelt along the entrance road was replaced during the 1990s but that renovation process was not continued. Remaining shelterbelt and landscape trees and shrubs are over-mature and are not maintained. Some are being lost from wind damage that is exacerbated by an infestation by boring insects. Limb breakage and toppling of trees has become common.

***References*:**

Annual Reports from the Sherman and Pendleton Stations (Appendices 5 and 6)

Letters sent to or from the Station Superintendents

Oveson, M. M. 1940. Examples of Accomplishments and Projects at the Sherman Branch of the Oregon Agricultural Experiment Station in Cooperation with the U.S. Bureau of Plant Industry from 1909 to 1940. An Unpublished Station Summary. 8 pages.

Ross, C. R. 1972. Eastern Oregon Windbreak Trees and Shrubs. Oregon State University Extension Service Special Report 371. 16 pages.

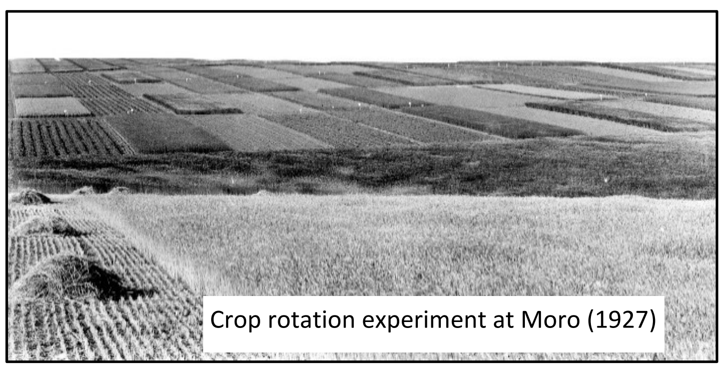
Chapter 12 - Crop Rotation Systems

Improvement of cropping systems has been a principal focus of the dryland agricultural research stations in Oregon. The scientists have made significant attempts to help farmers improve the profitability of farms and to prolong the productivity of soil by reducing the rate of decline in soil organic matter and by minimizing the amount of soil erosion caused by water and wind.

An early priority at both stations was to identify crops that could be rotated with wheat. Evaluations of crop rotations commenced almost immediately at both stations. In 1911, W. M. Jardine (USDA) and H. D. Scudder (OAES) designed a crop rotation experiment that was established by David Stephens at the Sherman Station in 1912 and terminated in 1953; after 42 consecutive years. The longest crop rotation experiment at the Pendleton Station was established by David Stephens and George Mitchell during 1931, and continued to be evaluated until 1953 (23 years). In 1950, Merrill Oveson established an off-station rotation at the Crow Pilot Farm, near Weston, and that rotation continued until 1964 (14 years). Dr. Richard Smiley studied two shorter-term (5 to 6 year) rotations on farms in Morrow and Union counties during the 1990s. Dr. Stephen Machado established a rotation experiment at the Sherman Station in 2004, and that experiment is still in progress (15+ years). These and several other rotation studies are summarized in this chapter.

Sherman Station (1912-1953)

The 1911 Annual Report revealed that an experiment with 14 rotations consisting of 60 plots was being established on 12 acres of land. A primary objective was to answer the question "*Can the great area now lying idle each year in summer fallow be reduced or even eliminated by proper sequence of grain and cultivated crops of grain, cultivated crops and manure crops?*" Another goal was as follows: "*The second great object of these rotations is to increase the humus so deficient in the eastern Oregon wheat soils and which is being rapidly reduced by the methods of cultivation now in vogue.*" Treatments were selected from among the most promising treatments being evaluated at branch experiment stations near Nephi, UT and Philbrook, MT. The wheat and barley rotations included summer fallow every second, third or fourth year, with crops of corn or peas in rotation with small grains, or no summer fallow in 3- or 4-year rotations that included one row crop (corn or potato) and one manure crop (pea or rye). Additional treatments were added periodically over the next three decades. For example, 21 treatments were being studied in 1917, 28 treatments in 1929, and 30 treatments in 1945. The focus was on comparing the profitability of each system, not just on crop yields.


Crop rotation experiment at Moro (1927)

Distinct trends in the carbon and nitrogen contents of surface soils had started to become evident in certain rotations within 10 years. During 1922, J.S. Jones and W.W. Yates sampled every plot of the experiment and made nitrogen and organic matter determinations. They published results in the Journal of the American Society of Agronomy (Jones and Yates, 1924), which appears to be the first professional journal paper to report results from the rotation experiment at Moro. Jones and Yates concluded that "*Summer fallowing is a necessary practice in dry-land agriculture of the Columbia Basin, but one that is generally conceded to be particularly exhaustive of the soil's content of organic matter and conducive to excessive losses of soil nitrogen*." "*Fallow crops, rye and field peas, turned under have thus far not all increased the organic matter content of the soil over that in plats alternately cropped to winter wheat and summer fallowed. Field peas turned under (the pea fallow) substantially enrich the soil with nitrogen. Nitrogen has thus far been maintained on plats that have grown field peas continuously, with crops removed, but organic matter is lower than in plats alternately cropped with winter wheat and summer fallowed*." Routine monitoring of those rotations continued until the experiment was terminated in 1953.

Only a few treatments were terminated prior to 1953. The decision to terminate a treatment was made when a specific treatment was clearly not providing promise of economic returns of interest to the growers. The long-term rotations experienced the vagaries of year-to-year and seasonal climate variables that are commonplace and to be expected. The highly repetitive nature of this work contributed to a nearly universal statement in introductions of all annual reports. That statement was something similar to the following: "*The experimental work carried on at the Sherman Branch Experiment Station in 1945 was in most part similar to that in 1944*." The introduction then continued with an overview of the changes and/or new trials conducted. While informative, annual data and observations from the rotations are not nearly as valuable and informative as the long-term trends for individual treatments. Nevertheless, the annual reports provided important insights, such as in 1920, when it was stated that all of the cereals have consistently produced lower yields after a green manure crop than after summer fallow.

Already by 1923, scientists at the Station concluded that winter wheat was the most valuable of the dryland crops. David Stephens, in a 15-page summary of the rotation experiments published in the 1923 Annual Report, concluded that "*the growing of winter wheat after fallow will likely for a long time remain the most popular method of growing this crop on the drier lands of eastern Oregon*." However, he also cautioned that "*the soil fertility problem incident to any one-crop system of farming may sometime compel a change in the present wheat-fallow system now so universally practiced in eastern Oregon. Or such a change may be brought about by difficulty in controlling noxious weeds, insect pests, or wheat diseases*." Stephens provided many reasons, including information of water-use-efficiency, the winter growth habit, the early maturation, superior yields, the availability of time during the fall, and others. Spring wheat also generally produced well but was not as profitable and, more importantly, needed to be planted during early spring when spring tillage for fallow and for other spring crops demanded a great deal of the farmer's time and effort. Further, they concluded "*Barley is admirably adapted to most sections of eastern Oregon and should have a prominent place in any rotation system which includes spring-sown crops*." Practical disadvantages of including oats, pea, rye, corn and potato in the rotations were also discussed.

In 1926, most of the rotation treatments had been in place for 14 years. Crops grown after fallow had 14-year averages of 41 bushels/acre (1,958 pound/acre) for barley, 28 bushels/acre (1,662 pound/acre) for winter wheat, 49 bushels/acre (1,558 pound/acre) for spring oats, and 23 bushels/acre (1,386 pound/acre) for spring wheat. Of the six rotations that included green manure crops, none showed any superiority from the standpoint of seed yield over other rotations, including grain crops grown with no fallow and with no green manure.

The number of treatments being examined was dramatically reduced in 1952. All 11 of the rotations that included corn as a component were discontinued because "*corn is not adapted to this dry land area* [due to] *low rainfall, lack of summer rains, cool night temperatures, and low yields of poor quality corn.*" After 40 years of evaluation, the overall corn yield averaged about 10 bushels per acre, and was of poor quality. The entire experiment was terminated in 1954, after being carefully discussed by a group of growers and scientists, and with concurrence of administrators at the University.

<u>Crop Rotations</u>

- An initial objective in establishing the Sherman Station was to find profitable rotations that would be beneficial to the soil resource in a wheat-based economy
- Elaborate rotation experiments were conducted from 1911 until 1953
- Emphasis for rotations was profitability as well as influences on soil fertility, organic matter, and soil moisture
- It was documented that winter wheat-summer fallow rotations produced the highest economic returns and the least year-to-year variability in grain yield
- Spring barley was well adapted and produced the highest economic returns of spring-planted crops
- Annual pea crops produced high yields but were not as profitable as wheat
- Wheat following fallow produced more grain than wheat following field pea as a green manure crop
- Corn or potato were not adapted to the environment; they did not produce high-quality products
- After crop rotations were terminated and planted to a winter wheat-fallow rotation, wheat yields continued to be greater for as long as 16 years where the old rotation plots had included pea either as a crop or a green manure
- Early rotation tests were conducted mostly without added fertilizer or pesticide, and may therefore be of value to current farmers who products without those inputs

The tables, charts and following statements were summarized from the 1951 Sherman Station Annual Report. As usual, the data were reported for the current year and also for the life of the experiment. Eighteen of the 30 treatments had been grown for 40 consecutive years, since 1912, while other treatments were reported for shorter time periods; four treatments for 38 years, two for 36 years, one for 35 years, five for 34 years, and one for 17 years. Also, as usual, all phases of each experiment were reported individually. For example, in the three-year rotation of spring wheat-spring barley-corn, there are three separate lines of data averaged over 40 years for spring wheat after corn, spring barley after spring wheat, and corn after spring barley. Data were also summarized over five-year intervals over the course of the experiment. Potatoes had been eliminated from the experiments during 1948. The long-term data are repeated in this review because they may be of value because the advent of chemical applications had been rather recent, except for the treatment of seed for smut control. These data were collected mostly without added fertilizers or pesticides for weed, insect and disease control, and could therefore be of value to modern producers who are serving the increasing demand for organic products.

Average acre yields of crops over the 40 years of seven rotation treatments in trials at the Sherman Branch Experiment Station; F = cultivated fallow, mF = manured fallow, pF = pea turned under fallow, rF = rye turned under fallow, WW = winter wheat, SW = spring wheat, SB = spring barley, SO = spring oat, Pe = pea, R = rye. Data for 21 rotations are not shown in this table because they contained corn and/or potato; including all rotations with no fallow, or with fallow once in four years.

Rotation number, group, and crops or management		Rotation phase	Years	Grain Yield (bu/ac)	Grain Yield (lb/acre)	Annualized Yield (lb/ac/yr)	Yield Rank
I. *Fallow once in two years*							
1-A	WW-F	WW after F	1912-1951	25.6	1,572	786	17
1-B	SW-F	SW after F	1912-1951	23.8	1,458	729	25
1-C	SB-F	SB after F	1912-1951	38.5	1,829	915	4
1-D	SO-F	SO after F	1912-1951	47.4	1,542	771	21
II. *Fallow once in three years*							
2	SW-SW-F	SW after F	1912-1951	23.5	1,410	702	27
		SW after SW	1912-1951	11.6	696		
3	SB-SB-F	SB after F	1912-1951	36.0	1,728	849	9
		SB after SB	1912-1951	17.1	821		
4	SW-SB-F	SW after F	1912-1951	23.9	1,434	768	19
		SB after SW	1912-1951	18.1	869		
25	WW-SW-F	WW after F	1918-1951	25.0	1,500	700	29
		SW after WW	1918-1951	10.0	600		
III. *Rotations with green manure crops*							
7	SW-SB-pF-F	SW after F	1912-1951	27.6	1,656	723	26
		SB after SW	1912-1951	25.7	1,234		
13	SW-SW-pF-SB	SW after SB	1918-1951	14.1	846		
		SW after SW	1912-1951	13.1	786	802	14
		SB after pF	1912-1951	32.8	1,574		

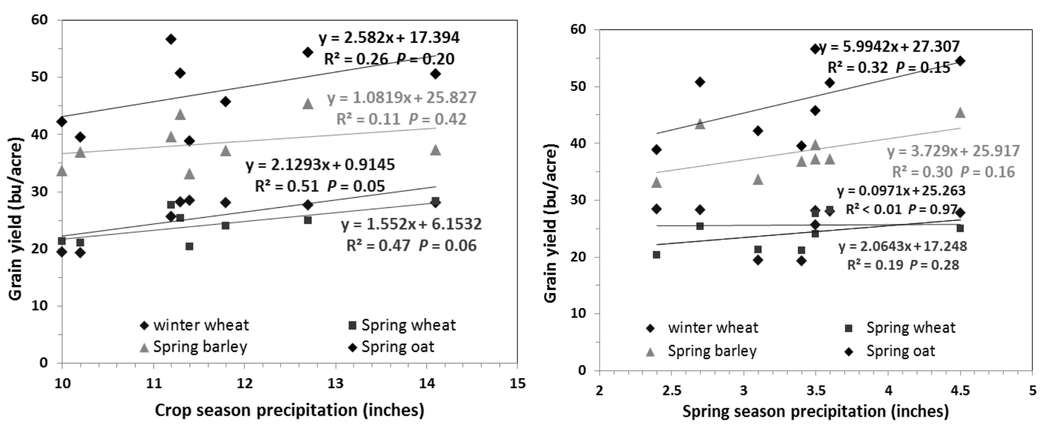
It was of particular interest that the winter wheat-fallow rotation (1-A) was considered the most widely practiced form of agriculture when the rotation experiments were established in 1912. Stephens and Hill (1917) reported that the principal crop in eastern Oregon was winter wheat, which occupied 75 percent of the cultivated acreage. Almost all winter wheat was rotated with summer fallow. That situation did not change during periodic updates from findings in the experiments at the Station (Stephens and Hyslop, 1922; Stephens 1924). In 1948, the winter wheat-fallow rotation ranked #17 in the amount of seed produced (grain yield minus seed planted). The 2-year spring barley-fallow rotation ranked #4.

It is of interest that the grain yields in 2-year grain-fallow rotations did not increase over time when summarized over eight consecutive time intervals (mostly 5-year intervals) during the life of the experiment (in the second table). This occurred for winter wheat, spring wheat, spring barley, and spring oats. This result suggests that although state-of-the-art varieties were being planted as they became available, climatic variables appeared to be more closely related to yield than was an introduction of new varieties. Winter wheat and spring wheat yields were significantly influenced by crop-season precipitation but not by spring precipitation. For spring barley, the spring precipitation was more important than the crop year precipitation but neither was closely associated with yield. Yields of spring oats were not significantly influenced by either measure of precipitation but the slopes of the regression lines showed an obvious trend for greater yields as the precipitation increased. These relationships are illustrated in the second table and the figure.

Average acre yields (bushels/acre) of grain crops over the 40 years of rotation trials at the Sherman Branch Experiment Station; each crop was in a 2-year grain-fallow rotation.

	1-A	1-B	1-C	1-D	Precipitation (in.)*	
Crop year interval	Winter wheat	Spring wheat	Spring barley	Spring oats	Crop Season	Spring season
1912-1917	27.7	25.0	45.4	54.4	12.7	4.5
1918-1922	28.4	20.4	33.2	38.8	11.4	2.4
1922-1927	28.2	25.4	43.5	50.7	11.3	2.7
1928-1932	19.4	21.3	33.7	42.2	10.0	3.1
1933-1937	19.3	21.1	36.9	39.5	10.2	3.4
1938-1942	28.1	24.0	37.2	45.7	11.8	3.5
1943-1947	25.6	27.6	39.7	56.6	11.2	3.5
1948-1951	28.0	28.3	37.3	50.6	14.1	3.6

* Crop season = September 1 to August 31; Spring season = March 1 to July 31



Relationship between grain yield and spring or crop-year precipitation over the 40-year history of rotation trials (1912-1951) at the Sherman Branch Experiment Station; each crop was in a 2-year grain-fallow rotation.

In the Annual Report for 1957, it was stated that plots that were in rotations from 1912 until 1953 are being uniformly cropped for the third year and large differences of winter wheat growth continue to be observed on the discontinued plots. Yields were therefore collected during 1957 to quantify the residual effects. Most old rotation plots yielded around 30 bushels/acre. Plots that had included a pea crop or peas turned under as a green manure yielded around 40 bushels/acre, even when peas were included only once in the four years of the rotation. The solid planting of winter wheat was harvested again in 1959 to determine comparative yields on the discontinued treatments. The highest yields (32-37 bushels/acre) in the fourth uniformly-planted winter wheat crop were from places previously occupied by Plots 6, 7, 12 and 13, each of which contained peas or a pea green-manure crop. Yields for the other 'old' treatments were 26-30 bushels/acre, which continued to be statistically significantly below that of old treatments with peas.

Nairn (1956) applied statistical analyses to evaluate data that had accumulated over 40 years from the crop rotation experiment at Moro. He concluded with the statement "*Only limited conclusions were derived from the rotation data because of large unexplained variations in yields*." However, Nairn reported that the most profitable rotation was the winter wheat-summer fallow rotation. Nairn also found the frequency at which summer fallow occurred in rotations did not affect the average level of wheat yields grown after summer fallow. Yields of spring wheat and winter wheat declined in wheat-fallow rotations during the study period. It was discussed earlier, and shown in the previous chart, that yields were quite well associated with precipitation during the spring or the entire crop season. Wheat yields were generally lower following another crop (pea, corn or potato) than after summer fallow. Peas, corn and potato were not economically viable crops at Moro because their yields would have had to be more than doubled to cover the costs of producing those crops. A three-year rotation including two grain crops and a summer fallow provided only 70 to 85 percent of the return compared to a two-year winter wheat-summer fallow rotation. Rotations that included a green manure crop were also only 75 percent as profitable as the winter wheat-summer fallow rotation. The 2-year winter wheat-fallow rotation continues to represent the vast majority of wheat acreage in Sherman County today, more than a century later.

Sherman Station (1952-1965)

A series of annual cropping experiments established during the early 1950s were continued and expanded in 1957. This was because summer fallow had always been practiced in the region "*to accumulate moisture and nitrates*." But many areas in the region have shallow soil which receives enough moisture in one winter to fill the entire soil profile. Also, by the 1950s, fertilizer had eliminated the need to accumulate nitrate during the fallow period, and erosion had been reduced by leaving stubble on the land each winter. Farmers still needed to know what amount of soil water was required in the spring to afford an opportunity to produce a crop on re-cropped land. They needed to know how much nitrogen could be applied economically, and whether they could produce yields each year that were equal to at least half the yield of winter wheat rotated with summer fallow. The crops in those trials included spring wheat (since 1952), winter wheat (since 1955), spring barley (new in 1957), and spring oats (new in 1957). During 1962, the annual spring wheat produced more wheat than wheat after summer fallow in all five of the 2-year periods for which data was collected. The annual cropping of winter wheat also produced more wheat than the winter wheat-fallow rotation during the 10-year period, although the yields from annual winter wheat were highly variable from year to year, including two total crop failures that were also included in the averages. The trials were continued and results were similar to those just stated.

Sherman Station (since 2004)

A more recent crop rotation experiment was established at the Sherman Station during the fall of 2003. This experiment was led by Dr. Stephen Machado (agronomist) and included observations, guidance and data collection by Drs. Dan Ball and Judit Barosso (weed scientists), Richard Smiley and Christina Hagerty (plant pathologists), Steve Petrie, Don Wysocki, Stewart Wuest and Hero Gollany (soil scientists), and Catherine Reardon (soil microbiologist). All of these scientists were or are located at the Pendleton Station. The primary aim of the study was the same as for the rotations examined during earlier years of the Sherman Station; namely, it is clear that the winter wheat-summer fallow rotation continues to reduce soil organic carbon, exacerbate soil erosion even under trashy fallow conditions, and is not biologically sustainable. Despite those concerns, very few alternative cropping systems have been established in the region. One reason is that there has been a lack of recent research on the long-term viability of alternate cropping systems. There were occasional crop failures in the long-term conventional-tillage, intensive-cropping experiments conducted at the Sherman Station from the 1940's until the 1960s. Additional research was required to examine the newest crop varieties and the newer agronomic practices and equipment used for direct seeding. This project therefore established a long-term experiment to compare the conventionally-tilled wheat-trashy fallow system with alternate cropping systems that used direct seeding to further reduce erosion caused by wind and water. The aim was to determine if any of the cropping systems could increase residue cover, soil organic matter, crop-available soil moisture, and sustained soil productivity while also reducing soil erosion and evaporative loss of soil water.

Current crop rotation experiment at Moro

Crop rotations for this experiment are shown in the table. Each phase for each of the eight rotations appears every year. There are therefore 14 large plots (48 × 350 feet) for the eight rotations within each of the three replicates. All agronomic practices and pesticides are in accordance with the best regional management practices for each crop in each rotation. All direct-seeded crops are planted with a Fabro® drill and the winter wheat in the conventionally-tilled rotation is planted with a John Deere HZ deep-furrow drill. Different fertilizer rates (10 to 50 pounds N/acre) were applied to plots of different rotations to equilibrate nitrogen levels to 80 pounds N/acre.

Baseline soil chemical data were collected at 12-inch depth increments to 6-foot depth in each of the 42 plots in 2003, before the experiment began. Other baseline data included documentation of water infiltration rates, aggregate stability, and numbers of earthworms. Each of these tests and microbial population and diversity were measured again in 2009, after two cycles of the 3-year rotations.

Treatments in the 2004 rotation experiment at the Sherman Station.

Rotation	Treatment	Rotation description	Tillage*
1	1 & 2	Winter wheat-conventional trashy fallow	CT
2	3 & 4	Winter wheat-chemical fallow	DS
3	5	Annual winter wheat	DS
4	6	Annual spring wheat	DS
5	7	Annual spring barley	DS
6	8, 9 & 10	Winter wheat-spring barley-chem. fallow	DS
7	11 & 12	Winter wheat-winter pea	DS
8	13 & 14	Flex crop**	DS

*CT = conventional tillage using high-residue ‘trashy’ fallow; DS = direct seeded (no-till).

** Two sequences of direct-seed flexible management treatments included crops and sequences based upon real-time decisions regarding current market prices and current and expected soil moisture. Crops in these flex-crop rotations included winter wheat, spring wheat, spring barley, spring pea, spring canola, yellow mustard and camelina.

Daily average data on precipitation, soil temperature, and air temperature were collected continuously. Annually, samples were collected to measure nitrate, ammonium and sulfur concentrations in soil, from which the fertilizer requirements were determined. Data were also recorded each year for plant stand density, dates of plant emergence, anthesis and maturity, adult plant biomass, grain yield, diseases, weeds, insect pests, soil moisture and erosion. Soil water measurements were taken throughout the growing season using a dielectric probe that sensed the soil moisture content at 4-, 8-, 16-, 24-, and 40-inch depths. Weeds were identified and densities were estimated during the spring. Diseases were monitored by identifying and rating the incidence (percent plants infected) and severity (qualitative severity scale) of diseases such as Fusarium foot rot, take-all, Rhizoctonia root rot, and Pythium root rot. The presence or absence of other diseases and insect pests was also recorded. Soil samples were collected and sent to commercial laboratories to identify and quantify plant-parasitic nematodes. Quadrats were sampled to measure plant biomass, grain yield, grain test weight, and harvest index (ratio of grain to plant biomass). The remainder of each plot was harvested using a commercial combine and grain was weighed using a weigh-wagon.

All inputs and outputs of each cropping system for documented. In 2008, an economic analysis was conducted in collaboration of agricultural economists from Oregon State University, Washington State University and University of Idaho. Annual and average grain yields were reported in the research center’s 2009 Special Report (Appendix 5), representing the fifth crop from this experiment but only the fourth crop with respect to reporting of meaningful results. The first year (2003-2004) was the establishment year. Treatments with 2-year rotations had completed a full cycle by late 2008. Two full cycles for 3-year-rotations would require an additional two years after this summary was presented. Yields of winter wheat, spring wheat, spring barley, and winter pea are shown in the table. The final year had the second-lowest crop year precipitation (8.4 inches) during the experiment, which resulted in reduced yields of annual crops.

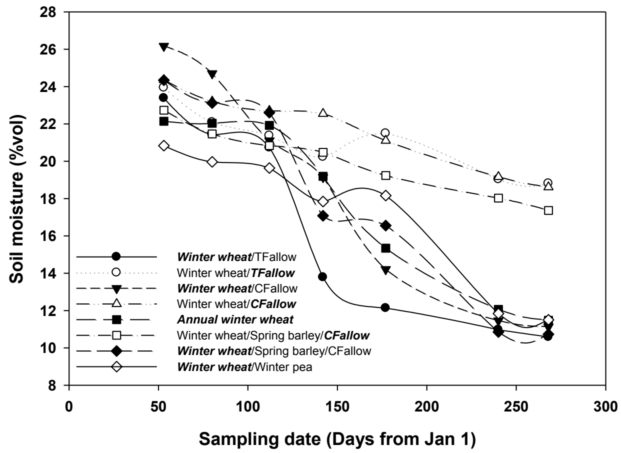
Yields of winter wheat after either conventional or chemical fallow were also significantly reduced because of low spring precipitation. Based on the 4-year average (2004-2005 through 2007-2008 crop-years), winter wheat following fallow in a 3-year rotation with spring barley produced the highest yields although these yields were not significantly different from yields of wheat after conventional tillage fallow.

The high wheat yield obtained from the 3-year rotation is partly attributed to low levels of root-lesion nematode incidences and low weed infestation. Yield from the 3-year rotation was significantly higher than yield of winter wheat following chemical fallow. Yields from annual crops were strongly influenced by annual precipitation. Annual spring barley, with the lowest root-lesion nematode incidences, produced the highest yield followed by winter wheat after winter pea, with the lowest root-lesion nematode incidences. Annual winter wheat produced the lowest yields over the four crop-years. This was attributed to a combination of high downy brome infestation during the first three years and high incidences of root-lesion nematodes, but not due to a shortage of water as was expected in annual cropping. Grain yields of all crops were negatively associated with root-lesion nematode incidences, as shown in the figure. In the first three years, soil moisture in plots grown to annual winter wheat was greater than in other rotations from May until harvest,

Grain yield of winter wheat, spring wheat, spring barley, and winter peas in the Sherman Station crop rotation experiment; 2004-2008. The yield shown is for the crop in italics.

Rotation	Grain yield (bushels/acre)				
Annual crops	2004-05	2005-06	2006-07	2007-08	Mean
Annual *winter wheat*	10.6c	18.7d	30.76ef	20.2bc	20.2e
Annual *spring wheat*	10.1c	37.9bc	32.01e	15.0c	23.9de
Annual *spring barley*	11.6c	64.8a	39.31d	24.2b	34.9c
Two-year rotations†					
Conventional fallow-*winter wheat*	58.0a	59.5a	64.5ab	38.9a	55.2ab
Chemfallow-*winter wheat*	52.9ab	46.5b	60.6b	41.4a	50.3b
Winter wheat-*winter pea*	9.1c	17.1d	9.5g	-	-
Winter pea-*winter wheat*	40.5ab	33.2c	36.4de	13.2cd	30.8c
Three-year rotations					
Chemfallow *winter wheat*-spring barley	63.2a	57.9a	65.9a	42.6a	57.4a
Winter wheat-*spring barley*-chemfallow	12.8c	59.2a	35.7de	9.5d	29.3cd
Precipitation (inches)	7.9	16.9	11.1	8.4	

†All plots are direct seeded except Rotation 1: Conventional fallow treatments.



Average soil water content under all rotations in the 0- to 40-inch depth profile in 2008. Data shown are for the crop or treatment in boldface and italics of a rotation; TFallow = cultivated fallow and CFallow = chemical fallow.

indicating that the crop was not able to use available soil moisture, likely due to the combination of root damage caused by root-lesion nematodes and Fusarium crown rot. Both of these diseases restrict the uptake of water by roots and the transmission of water from the roots to the foliage. Crop rotations that involved spring barley had very low incidences of the root-lesion nematode and consequently produced high yields.

Soil moisture (average of whole 40-inch profile) for each treatment in 2008 is shown in the figure. Results were comparable during other years. As expected, fallow treatments contained the most moisture throughout the season. The amount of water stored in the fallow treatments decreased with time from spring to fall. The chemical fallow treatment (Table 1, rotation 6) had the lowest soil moisture from the start to the end of the measurements. Moisture in plots with crops decreased as the season progressed due to increased evapotranspiration. Soil moisture in plots grown to winter wheat after fallow decreased the most. In 2006 and 2007, moisture in plots grown to annual winter wheat remained higher than in other cropped plots throughout the season, indicating that wheat under that treatment was unable to use the available moisture, which was attributed mostly to the roots injured by high populations of root-lesion nematode.

Weeds that became a concern during the early years of the experiment included downy brome, particularly in annual direct-seed winter wheat. Other weeds of less importance included prostrate knotweed and prickly lettuce. Tumble mustard increased and became of particular importance in the spring crops. The planting of the wheat variety ORCF 101 Clearfield (resistant to imazamox) during the fall of 2008 and spraying of that crop with imazamox (Beyond®) herbicide in 2009 greatly reduced, but did not eliminate, the contamination of direct-seeded winter wheat by downy brome. In plots of annual winter wheat, however, downy brome populations were reduced from 41 plants/m^2 in 2007 to 6 plants/m^2 in 2008 by the newly developed Clearfield wheat technology. Rattail fescue was also evident in direct-seeded, annual winter wheat, which is often also a problem in commercial, direct-seeded winter wheat. Prickly lettuce and prostrate knotweed densities were high in winter wheat grown in rotation with pea. This was due to less effective late-season control of those weed species in the previous winter pea crop.

Root diseases of greatest importance included Fusarium crown rot, Rhizoctonia root rot, Pythium root rot, and root-lesion nematodes, all of which were affected by specific treatments (Smiley et al., 2013b). Fusarium crown rot was generally highest where winter wheat was sown into the 2-year rotations of winter wheat with either summer fallow or winter pea. The incidence of this crown rot disease of winter wheat was higher when the wheat was planted early into cultivated fallow compared to wheat planted later into chemical fallow. However, crown rot was also extensive on spring wheat and spring barley. Rhizoctonia root rot and take-all were also prevalent at low- to intermediate-levels on all cereal crops but there were no definitive differences in these diseases in response to the different rotation treatments. Similarly, there were significant differences among disease ratings for the various broadleaf crops.

Number of root-lesion nematodes (RLN) averaged over five years; from 2004 until 2008

Rota-tion	Treat-ments	Rotation description	RLN/lb of soil
1	1 & 2	Winter wheat-conventional trashy fallow	1,645
2	3 & 4	Winter wheat-chemical fallow	1,414
3	5	Annual winter wheat	2,653
4	6	Annual spring wheat	1,900
5	7	Annual spring barley	626
6	8, 9 & 10	Winter wheat-spring barley-chem. fallow	1,032
7	11 & 12	Winter wheat-winter pea	2,057
8	13 & 14	Flex crop	1,513

Root-lesion nematodes are plant-parasitic nematodes detected in high numbers in some treatments of this experiment. Nematode numbers varied from year to year and also in response to different phases of the 2- and 3-year rotations (Smiley and Machado, 2009; Smiley et al., 2013a). For instance, nematode numbers were generally lowest following barley crops and were highest following direct-seeded winter wheat, winter pea, and oilseed crops such as yellow mustard. A 5-year average, determined after the 2008 crop, is shown in the table. Lowest numbers occurred in the annual spring barley and in the 3-year rotations that included spring barley and chemical fallow. Highest numbers were in the annual winter wheat and in the winter wheat-winter pea rotation.

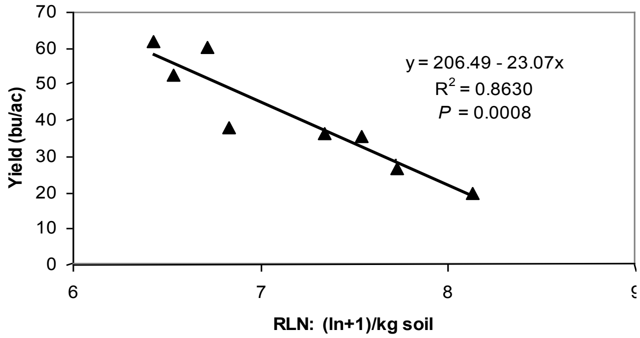
Another way to examine the influence of crops and rotations on nematode numbers is to evaluate the data set grouped according to the previous crop or management. Numbers of nematodes were highest following crops of winter wheat, winter pea and yellow mustard, and were lowest following spring barley and chemical fallow. In other experiments, it was determined that spring barley is a relatively poor host for these nematodes, which need the presence of living roots of ‘good’ host plants in order to multiply. Most varieties of winter wheat, winter pea, yellow mustard and many other crops are known to allow prolific multiplication of these root parasites.

Number of root-lesion nematodes (RLN) during early spring following a specific crop or management practice over a 5-year period (2004-2008)

Previous crop or management	RLN	n*
Winter wheat	2,276	63
Yellow mustard	1,839	3
Spring wheat	1,035	65
Winter pea	2,520	12
Spring barley	967	27
Conventional fallow	1,160	12
Chemical fallow	971	30

*n = the number of plots that occurred for a specific treatment over the first 5 years in the experiment

In comparisons of nematode numbers in soil and the yields of cereal crops in these experiments, when averaged over crop years, it was determined the number of root-lesion nematodes was negatively correlated with the grain yields, as shown in the following chart. Smiley concluded that 86 percent of the yield variability for these crops was due to the variable numbers of root-lesion nematodes, even though the environment at this location is very dry, particularly during the summer and early fall. This conclusion was supported by the fact that the crops planted into plots with the highest nematode numbers failed to extract all of the available water in the soil profile. In extreme instances, winter wheat in plots with high numbers of nematodes only used half of the amount of water used by wheat in plots with low numbers of nematodes.



Relationship between root-lesion nematode numbers (RLN; expressed as the log transformed number/kg of soil) and yields for winter wheat, spring wheat, and spring barley averaged over three crop years (2005-2007) in the 2004 rotation experiment at the Sherman Station.

Dr. Machado reported a partial net economic analysis of this rotation experiment in the research center's Special Report for 2008. The analysis was made for the continuous cereals, wheat-fallow rotations, and the 3-year rotations by subtracting the variable input costs from the gross crop value. Variable input costs for herbicides, fertilizer, and seed were based on the invoices for the products. Tillage, herbicide and fertilizer application, and seeding costs (labor, equipment repairs, fuel, depreciation, etc.) were based on the Oregon State University Enterprise Budgets for Winter Wheat (such as Seavert et al., 2012). The costs of flailing and seeding using a direct-seed drill were estimated. Costs were broken into the crop input (planting through harvest) and the fallow phase (harvest through seeding). Crop value was determined by multiplying the crop yield by the grain prices in Portland during October. The analysis did not include counter-cyclical payments, loan deficiency payments, crop insurance, or fixed costs such as cash rent or taxes. The standard deviation of the average was determined as a measure of variability from year to year. Data from Machado showed that wheat-fallow rotations were most profitable if they were managed with the conventional trashy fallow system. The annualized total 2-year partial net return (crop value – fallow cost) was $32.71/acre greater for tillage fallow and conventional seeding compared to chemical fallow and direct-seeding. The annual cost of tillage-based fallow was less than the average cost of chemical fallow, and the variability (standard deviation) of fallow costs was much greater for chemical fallow than conventional fallow. There were usually as many herbicide applications each year in the chemical-fallow treatments as there were rod-weeding operations in the tillage-fallow treatments, except that five herbicide applications were made in the summer of 2007 to the chemical-fallow treatment. Crop value was consistently greater in the tillage fallow because the yields were greater. The average crop value was $44.69/acre greater in the tillage fallow and conventional seeding than in the chemical-fallow and direct-seeding treatments. The crop value in 2007 was more than double the crop value in 2005 and 2006 because wheat prices rose to record levels in the fall of 2007. The Portland wheat price in 2007 was $9.25/bushel compared to the previous 36-year average of $3.69/bushel.

Comparison of fallow costs, variable cost inputs, crop value, and partial net returns from winter wheat in conventional fallow and chemical fallow rotations at Moro, Oregon, 2004-2007.

Input	Year			Average	Std Dev
	2004-05	2005-06	2006-07		
Fallow phase	------------------- $/acre -----------------------				
Chemical fallow	40.16	57.02	77.35	58.18	18.60
Tillage fallow	38.10	35.76	32.72	35.53	2.70
Difference	2.06	21.26	44.63	22.65	
Crop value					
Direct seeding	190.97	228.12	546.67	321.92	195.52
Conventional tillage	216.60	291.24	592.00	366.61	198.73
Difference	25.63	63.12	45.33	44.69	

Crop Input Costs					
Direct seeding	65.23	65.15	90.42	73.60	14.57
Conventional tillage	90.35	53.96	82.28	75.53	19.11
Difference	25.12	11.19	8.14	1.93	
Partial net return					
Direct seeding – chem fallow	125.74	162.97	456.25	248.32	181.03
Conventional tillage	126.25	237.28	509.72	291.08	197.31
Difference	0.51	74.31	53.47	42.76	
Annualized partial net return					
Direct seeding – chem fallow	42.79	52.98	189.45	95.07	81.89
Conventional tillage	44.08	100.76	238.50	127.78	99.98
Difference	1.29	47.78	49.05	32.71	

Continuous cropping using direct-seeding provided essentially continuous soil cover and offered the greatest potential to reduce erosion and halt the decline of soil organic matter of the cropping systems that were studied in these trials. Yields were low in 2005 for all cereal crops because the crop year precipitation was 7.9 inches compared to the long-term average of 11.9 inches. The following table shows that average annual input costs for continuous winter wheat was greater than for spring wheat or spring barley. This difference was attributed to the need for more herbicides in continuous winter wheat than in the spring crops. Input costs for spring wheat were greater than for spring barley due to increased seed cost and slightly higher nitrogen rates. The annual partial net return for continuous winter wheat was much more for continuous spring wheat and continuous spring barley than for continuous winter wheat.

A 3-year rotation consisting of winter wheat-spring barley-chemical fallow has two crops in three years and places the winter wheat immediately after the fallow to maximize the yield potential of the higher-valued cereal in the rotation. With direct seeding, this rotation provides continuous soil coverage to minimize erosion. The fallow phase also provides an opportunity for improved weed control and for storing moisture for the winter wheat crop. The following table shows that the crop value varies for each cycle of the rotation because the prices for crops, fuel and fertilizer vary during the 3-year cycle. These variables were overcome by annualizing the partial net return. The average partial net return was \$119.57/acre with a standard deviation of only \$28.41, which was the smallest standard deviation of any rotation that was being examined.

Comparison of variable cost inputs, crop value, and partial net returns from continuous winter wheat, spring wheat, and spring barley at Moro, Oregon, 2004-2007.

Input	Year			Average	Std Dev
Crop	2005	2006	2007		
	---------------------- \$/acre† ------------------				
Continuous winter wheat					
Input costs	80.79	59.84	67.13	69.25	10.63
Crop value	38.27	91.45	284.90	138.20	129.79
Partial net return	(42.52)	31.61	217.77	68.95	134.10
Continuous spring wheat					
Input costs	49.02	51.28	70.22	56.84	11.65
Crop value	36.46	187.37	296.00	173.28	130.34
Partial net return	(12.56)	136.09	225.78	116.44	120.48
Continuous spring barley					
Input costs	42.32	45.37	61.67	49.79	10.41
Crop value	28.70	244.80	249.10	174.20	126.03
Partial net return	(13.62)	199.43	187.43	124.41	119.69

† Parentheses indicate loss

The summary partial net returns for the cereal-based rotations after one 3-year cycle of the 3-year rotation are shown in the following table. Winter wheat tillage-fallow resulted in the largest average partial net return, followed by continuous spring barley and the 3-year rotation. The standard deviations of partial net returns of continuous cropping were much higher than those for 2- or 3-year rotations, indicating that annual cropping was a riskier economic venture than growing winter wheat in 2- or 3-year rotations. The 3-year rotation had the lowest standard deviation, indicating that the partial net return for that treatment was most stable over time.

Comparison of variable cost inputs, crop value, and partial net returns from the winter wheat-spring barley-chemical fallow treatment at Moro, Oregon, 2004-2007.

Crop	Cycle			Average	Std Dev
	1	2	3		
	$/acre†				
Fallow	56.81	42.12	53.76	50.90	7.75
Winter wheat					
Input costs	83.16	61.85	66.73	70.58	11.16
Crop value	601.25	282.79	228.15	370.73	201.50
Partial net return	518.09	220.94	161.42	300.15	191.07
Spring barley					
Input costs	42.32	63.83	69.95	58.70	14.51
Crop value	31.78	227.90	244.80	168.16	118.41
Partial net return	(10.54)	164.07	174.85	109.46	104.06
Annualized partial net return	150.25	114.30	94.17	119.57	28.41

† Parentheses indicate loss

Machado and his fellow scientists will update this analysis after two full cycles of the 3-rotations are completed. They also cautioned that this partial economic analysis did not include other forms of income such as counter-cyclical payments, loan deficiency payments, crop insurance, fixed costs for cash rent or taxes, or Conservation Security Program payments. The addition of these costs and payments would have changed the net returns and would have possibly affected the ranking of these rotations. Finally, and very importantly, this analysis did not include offsite or societal costs that are caused by soil erosion, loss of soil organic matter, and factors such as soil quality and sustainability.

Average annualized partial net returns from cereal-based rotations at Moro, Oregon, 2004-2007.

Rotation	Annual partial net return ($/acre)	Std Dev
Conventional fallow - winter wheat	127.78	99.98
Chemical fallow - direct seed winter wheat	95.07	81.89
Continuous spring wheat	116.44	120.48
Continuous spring barley	124.41	119.69
Continuous winter wheat	68.95	134.10
Winter wheat - spring barley - chemical fallow	119.57	28.41

Pendleton Station (1931-1953)

David Stephens and George Mitchell established a crop rotation experiment at the Pendleton Station in 1931. It was terminated in 1953. The experiment was almost identical to the previously summarized experiment at the Sherman Station. There were a few different treatments due to the higher rainfall at Pendleton than at Moro. This experiment initially contained two replicates of 35 rotation treatments. All phases of each rotation were planted each year, allowing data for each phase to be collected annually. The crops and varieties planted each year were documented. The rotations were divided into six groups; 1) land alternately cropped and fallowed, 2) continuous cropping, 3-5) 3-, 4- and 6-year rotations that include a single year of cultivated fallow, and 6) rotations in which one year of a green manure crop was included.

Annual and long-term average yields were tabulated and presented each year in the Pendleton Station Annual Report. For instance, in the 1949 report, Merrill Oveson presented 53 single-spaced typed pages of data and summary statements for this experiment alone. The data included annual yields since 1931 to 1949, mean yields during the 19-year period, and mean yields during the latest 10-year period (1940-1949). Average winter wheat yields (bushels/acre) after the following treatments were: wheat after a manured fallow (52), manure top-dressing of standing wheat rotated with fallow (50), 3-years of alfalfa and then fallow (49), bare fallow (46), peas (31), corn (37) or winter wheat (13). Average spring wheat yields (bushels/acre) were as follows for wheat after fallow (44), peas (31), corn (27), barley (19), spring wheat (16) or winter wheat (14). Yields (bushels/acre) of peas after the following crops were: winter wheat (28), peas (26), spring wheat (26), or sweet clover that followed winter wheat (20). A table shown in the 1946 report compared 6-year average yields following summer fallow, indicating the following ranking; spring barley (1,431 pounds/acre), winter wheat (1,281), and spring wheat (1,269), and spring oats (995). Corn produced most grain when it was planted after green manure crops of rye (18 bushels/acre) or pea (16 bushels/acre). Yields for other crops and sequences were also presented in detail but won't be summarized here.

Oveson's report in the 1953 Annual Report presented the most recent 10-year average wheat yields listed in a decreasing order of productivity for sequences in which the winter wheat crop followed fallow or another crop; manured fallow (50 bushels/acre), manure top dressing (49), alfalfa and fallow (48), sweet clover and fallow (45), fallow (45), pea fallow (43), corn (35), peas (31), and winter wheat (10). Similar reports were made for 10-year average wheat yields in which the spring wheat crop followed fallow or another crop; fallow (42 bushels/acre), pea fallow (42), clover green manure (34), peas (33), corn (25), winter wheat plus 30 pound N/acre (23), winter wheat (15), spring barley (15), and spring wheat (13). Similar averages for spring barley were highest after fallow (60 bushels/acre), intermediate after corn (31), and lowest after winter wheat (22). Top-ranking rotations with respect to average total annual seed production over the full 23-year period were as follows: winter wheat-pea, spring wheat-pea-pea, spring wheat-pea, and winter wheat-manured fallow. It was interesting that the 'standard' practice for the area, the winter wheat-fallow rotation, ranked #20 in the list of 35 rotation treatments.

The rotation experiment was terminated after the crop during 1953 because 1) crop sequences being studied left no difference in productivity of wheat following a year of fallow, 2) wheat after wheat had reduced yields, 3) wheat productivity was increased 14 bushels/acre when it followed a pea or corn crop, 4) rotations that included green manure crops (pea, sweet clover, or barley) did not increase wheat productivity and made the green manure crops "*definitely uneconomical*", 5) including alfalfa in the crop sequence increased wheat productivity by 10 bushels/acre.

Brown and Oveson (1960) published an economic treatise to summarize the rotation treatments that still existed when the experiment was terminated. The table on the next page shows the profit over operating costs for each treatment, as compared with the winter wheat-fallow rotation, which had a profit margin of $31.35 over operating costs, using 1955 prices. The comparative profitability of a winter wheat-fallow rotation fertilized with 60 pound N/acre was 20 percent above that of non-fertilized winter wheat-fallow.

After terminating the 1931 rotation experiment, the area was plowed, fertilized uniformly with 30 pound N/acre, and then planted uniformly to spring wheat in 1954. The crop was harvested in a manner that examined residual effects from the previous crop rotations. The following observations were made: 1) The crop sequences left no differences in the productivity of spring wheat following summer fallow, 2) wheat following wheat in the sequence yielded 14 bushels/acre less than when wheat followed corn or peas, and 3) inclusion of green manures (either pea, sweet clover or barley) did not increase the productivity of the soil as measured by wheat yields, making it unequivocal that green manure crops were uneconomical under conditions at the Pendleton Station. As shown in the table, the greatest 22-year average profitability over operating costs was achieved with rotations of winter wheat or spring wheat with peas, or of those crops in a 3-year rotation with fallow.

After the spring wheat was harvested the entire area was plowed in the fall and, in 1955, the area was planted uniformly to dry peas. Pea yields did not differ as a result of the previous crop sequences, but the pea yields were inversely proportional to the spring wheat yields in 1954. Pea yields were reduced following rotation sequences that had included a green manure component, as compared to a cereal crop without a green manure.

The experimental area was then planted annually as a winter wheat-dry pea rotation, with wheat being harvested in even-numbered years. The yield of the 1956 wheat crop was inversely proportional to the pea yield in 1955. However, winter wheat yields were also 14 bushels/acre higher where previous wheat crops followed corn or peas compared to wheat following wheat, and wheat yields were 10 bushels/acre higher if the previous rotation included alfalfa crops, as compared to an absence of alfalfa in those rotations. In 1958, yields of winter wheat were improved slightly in plots where green manure crops, peas, or alfalfa had been grown previously, even though the alfalfa forage had been removed for hay. These observations were made in comparison to wheat rotations that had not included green manure, peas or alfalfa. The 1960 winter wheat crop on the old rotation experimental area was again harvested in accordance with the previous rotations, using two 12-foot-wide and 12-foot-long swaths by the self-propelled combine in each of the old plots. Wheat yields were again increased in all plots where green manure or alfalfa crops had been grown, even though the alfalfa had been cut and removed as hay. Previous pea crops and use of barnyard manure also very slightly increased the wheat yields. As discussed previously, in Chapter 8, the residual benefit of alfalfa production to yield of winter wheat was shown through the fifth crop of wheat. In this rotation study, the positive benefit from previous production of alfalfa extended through the sixth crop of wheat, or over a period of 12 years.

Profitability of treatments in the 1931 crop rotation experiment at Pendleton

Cropping system group and rotation treatments*	% profit margin**
Group 1. Land alternately cropped and fallowed:	
winter wheat–fallow	100
spring wheat–fallow	101
spring oats–fallow	39
winter barley–fallow	56
spring barley-fallow	67
Group 2. Three-year rotations including one year of fallow:	
spring wheat–oats–fallow	80
spring wheat–fallow-field pea	135
spring wheat–field pea–fallow	128
winter wheat–spring wheat–fallow	94
winter wheat–spring barley–fallow	86
winter wheat–fertilized spring wheat–fallow	103
winter wheat–winter wheat–fallow	87
spring wheat–spring wheat-fallow	94
Group 3. Continuous cropping:	
spring wheat–field pea-field pea	161
spring wheat–field pea-field pea-field pea	144
spring wheat–corn–spring barley	55
winter wheat–field pea	148
spring wheat–field pea	149
Group 4. Rotations including a green manure crop:	
winter wheat–spring barley–peas turned under–corn	71
winter wheat–spring barley–rye turned under–corn	60
Group 5. Four-year rotations including one year of fallow:	
winter wheat–corn–spring wheat–fallow	81
Group 6. Six-year rotation including alfalfa and one year of fallow:	
winter wheat–corn–alfalfa (3 years)–fallow	84

*Data are not presented for 21 rotations which were terminated before 1953 because it became obvious that they were not economically or agronomically viable. Those rotations were as follows. Group 1 (winter wheat–manured fallow, winter wheat with manure top dressing–fallow), Group 3 (spring wheat–oats–corn with 3 tillage variables --disk vs. plow, or spring vs. fall, spring barley–oats–corn, oats–spring barley–corn, oats–spring wheat–corn, winter wheat–beans, spring wheat–beans, winter wheat–corn, fertilized winter wheat–corn), Group 4 (winter wheat–sweet clover–sweet clover), Group 6 (2 or 3 years of alfalfa followed by 2-year rotations of fallow with winter wheat, spring wheat, spring barley or oats).

**Profit margin was based upon a comparison with winter wheat-fallow, which was set as 100%.

Pendleton Station (Annual Cereals Since 1929)

While not a rotation, cereals have been planted annually at the Pendleton Station since 1929. The experiment serves as a comparison for wheat and barley grown in rotations. The experiment was established by George Mitchell and Dave Stephens to determine the best method for preparing a seed bed for continuous production of cereals. They quickly determined that yields were

greatest when fields were plowed immediately before planting winter and spring cereals. They therefore began that practice in 1931, as explained for this experiment in Chapter 6.

Numerous changes to this experiment have occurred since 1929. Since 1982, there have been blocks of winter wheat, spring wheat and spring barley, each of which have been planted annually into a plowed seedbed. The blocks were fertilized with 80 pound N/acre from 1982 to 1995, at which time a narrow strip through each block began to receive no fertilizer, to allow comparisons with the remaining fertilized portion of those crops. In 1997, a companion experiment in which the soil is not cultivated was established across the road from the original cultivated annual cereals experiment.

The most recent summary of results was published in the research center's 2007 Special Report. In both cultivated and no-till cropping systems, spring barley produced significantly higher yields than spring wheat or winter wheat. Winter wheat yields were 17 percent higher under cultivation than under no-till. Spring barley and spring wheat monocultures produced grain yields that did not differ significantly for tilled and no-till systems. Yields are significantly higher in the fertilized segment of each cereal in both cultivated and no-till experiments. The number of heads/square foot was also increased by fertilization in all except the tilled winter wheat. The unfertilized spring cereals produce only about two-thirds as many heads as in the fertilized crops. Spikelets/head are also increased by fertilization but kernels/head were not significantly affected by fertilizer except in the no-till winter wheat. Fertilizer increases the grain protein content in all of these monocultures. In fertilized and unfertilized monocultures, the tilled treatments have grain protein levels of about one percent lower than their no-till counterparts. Nitrogen uptake was not significantly different between tilled and no-till monocultures.

Pendleton Station (1942-1964)

George Mitchell, after being promoted in 1938 from Assistant Superintendent to Superintendent, initiated additional rotation experiments at nearly yearly intervals during the early 1940s. One of those rotations was established in 1942 and continued to be monitored until 1964. It consisted of a 16-year rotation of wheat and fallow after two, three or four years of alfalfa. During the late 1940s the various treatments had different numbers of wheat crop, i.e., one, two, three, four, or five wheat crops after the alfalfa had been taken out. The first wheat crop after alfalfa often ran out of water and suffered late-season drought stress. The residual benefit from the previous alfalfa plantings was greatest in the second and third wheat crops, and that benefit started to fade in the fourth crop. However, benefits of the alfalfa treatment, compared to wheat-fallow without alfalfa, were repeatedly observed into the fifth crop of wheat, 10 years after the alfalfa had been taken out. This observation was made in 1954, 1956, 1958, 1960, 1962 and 1964. Although there was usually no measurable benefit to the sixth crop of wheat, they measured a very slight but absolute one percent increase in wheat yield during the sixth crop of wheat, 12 years after the alfalfa stand had been plowed. This confirmed the long-lasting benefits of alfalfa in the previous rotation trials. The increased growth of wheat after alfalfa had been taken out was shown to be slightly superior to applying 60 pound N/acre into adjacent fallow land in the same area.

Pendleton Station (1944-1954)

A rotation was initiated at Pendleton in 1944 to evaluate effects of green manure (sweet clover or sweet clover plus grasses) in rotations of winter wheat and green peas. After 11 crop years, in 1954, the average yields showed that wheat after fallow without green manure averaged 36.3 bushels/acre, winter wheat after fallow with green manure averaged 46.6 bushels/acre, and winter wheat after green peas averaged 28.3 bushels/acre. Annual cropping with a wheat-pea rotation maintained organic matter as high as where green manure had been used in the rotations. Therefore, there was no benefit from the green manure and the cost of that practice was very high. In 1953, Federal and State cooperators met at Corvallis to redesign this experiment. They concluded that commercial fertilizer applied to fallow before growing winter wheat would increase yields much more than could be achieved by the green manure, and do so at considerably less expense and without deteriorating soil quality. Again, it was concluded that green manure was not economically viable for producing winter wheat at Pendleton.

Pendleton Station (Wheat-Pea Rotation Since 1963)

A wheat/pea rotation with tillage variables was established in 1963 by Dr. Robert Ramig and Merrill Oveson. The description and findings from that experiment are described in Chapter 13. The experiment was first called the "*cloddy seedbed experiment.*" Its objective was to determine the effects of four tillage regimes on soil properties and productivity in a winter wheat-spring legume annual crop rotation. Early results prompted green pea producers to request that the experiment be expanded and replicated at six off-station sites to compare results on two other soil series in Umatilla County. Water-use efficiency and crop yield data were collected at each location. Green canning peas produced 308 pounds for each inch of water extracted and NuGaines winter wheat produced 3.38 bushels for each inch of water. The off-station sites were terminated after three years but the study at the Pendleton Station is still being continued.

A summary of recent results from this experiment was published by Awale et al. (2018). Wheat yields are higher when soil is moldboard- or chisel-plowed, as compared to the no-till treatment. Reduced grain yields in the no-till treatment are consistently associated with higher densities of downy brome. Pea yields are lower in the fall plow treatment compared to the other three tillage treatments. Yields in all treatments are strongly responsive to winter precipitation and to precipitation and temperature during the growing season.

Pendleton Station (USDA Continuous No-till Winter Wheat Since 1997)

In 1997, Dr. Dale Wilkins converted a small section of the continuous annual winter wheat experiment to no tillage. The land had been plowed annually since 1929. Crop years 1998 and 1999 included two no-till drill treatments in addition to different fertilizer types, rates, and placement. From crop year 2000 to present, the drill used, fertilizer regime, and seeding rate have been relatively unchanged. A pre-seeding application of glyphosate is made each fall. A ConservaPak drill is used to plant winter wheat after mid-October. The drill delivers dry fertilizer down the fertilizer shank below and to the side of the seed. Application of fertilizer is made at rates of 105 pound/acre of 16-20-0-14 S and 185 pound/acre of 46-0-0, for a total of 112 pound N/acre. Weeds, insects and diseases are controlled using pesticides. Standing stubble is flailed after harvest.

In 2002, a imazamox-tolerant variety of winter wheat (Clearfield® technology) was planted and the crop and weed foliage was sprayed with imazamox herbicide. Use of that technology essentially eliminated the problem with annual grass weeds such as downy brome. Yields are quite variable from year to year, but only the first nine crops are reported because annual reports are no longer prepared by scientists at the Pendleton Station. Yields for nine crops, from 1998 to 2006, average 70.5 bushels/acre, with a range from 55 to 84 bushels/acre. For the same years, test weights average 57.8 pound/bushel, with a range from 56 to 61 pound/bushel. Yields were not correlated with winter precipitation and were very poorly correlated with spring precipitation and crop-year precipitation.

Crow Pilot Farm (1950-1964)

Four rotations were established by Merrill Oveson on a leased field near Weston. This field was one of three ‘Pilot Farms’ established for long-term off-station research (see Chapter 5). The rotations were designed to determine the benefits of soil building properties for growing spring wheat and pea. Rotations consisted of 3-, 4- and 5-year sequences to incorporate sweet clover as a green manure crop. Averaged over four years, the spring wheat yields were 10 bushels/acre higher when wheat followed pea or a fallow made by turning under sweet clover. The increase in wheat yield following the sweet clover fallow was considered inadequate to compensate for the loss of a pea crop during the year in which the sweet clover fallow was produced. Peas produced 500 pounds/acre less when grown as a companion crop than where peas were grown alone. The experiment was therefore re-designed during 1955. The two green manure rotations were terminated and a wheat-fallow rotation and a continuous wheat treatment were added. Also during 1955, all wheat was shifted to production of winter wheat, with the discontinuance of spring wheat production. A commercial fertilizer variable (0, 40, 80, and 120 pound N/acre) was also incorporated into the rotation scheme. The following five treatments were studied from 1955 until 1964, at which time the rotation experiment at the Crow Pilot Farm was terminated.

1. winter wheat-pea
2. winter wheat-(pea + sweet clover)-sweet clover green manure
3. (pea + sweet clover)-sweet clover fallow-winter wheat-pea-winter wheat
4. winter wheat-fallow
5. continuous winter wheat

Merrill Oveson’s 1960 Annual Report for the Pendleton Station stated that the 10-year average yield for wheat after peas was 44 bushels/acre without additional fertilizer, and 54 bushels/acre when 40 pound N/acre was added. The 10-year average yield for wheat after clover green manure was 54 bushels/acre without additional fertilizer, and 62 bushels/acre when 40 pound N/acre was added. The 10-year average yield for wheat after fallow was 46 bushels/acre without additional fertilizer, and 58 bushels/acre when 40 pound N/acre was added. The 10-year average yield for continuous wheat was 20 bushels/acre without additional fertilizer, 34 bushels/acre when 40 pound N/acre was added, 46 bushels/acre when 80 pound N/acre was added, and 56 bushels/acre when 120 pound N/acre was added.

Oveson summarized key findings of the experiment in the 1964 Pendleton Station Annual Report. The summary statements were as follows.

1. Where wheat is grown after peas, an addition of 40 pound N/acre at planting time increased wheat yields an average of 8.2 bushels/acre.
2. The growing of clover green manure in the rotation increased wheat yields over rotations where no green manure was used by about 12 bushels/acre.
3. When wheat was grown on regular fallow in a wheat-fallow rotation, yields were only slightly higher than where wheat was grown after peas with or without nitrogen added a planting time.
4. When wheat was grown continuously, increases in wheat yields were increased with additional increments of nitrogen of 40 pound up to 120 pound N/acre. This difference was much more pronounced during the first four years than over the last four years of the experiment.
5. Average pea yields when grown without clover were higher than when grown with clover as a companion crop.

John Cuthbert Farm (1986-1992)

The cereal cyst nematode was discovered in several Union County fields during 1984. A survey of cultivated fields in that county during 1986, by Dr. Richard Smiley and Gordon Cook, revealed that two-thirds of the surveyed fields were infested by that nematode. The only known and reliable method for minimizing root injuries by that parasite in other regions of the world was to establish crop rotations that included broadleaf species interspersed with cereal crops. While nearly all cereal crops are good hosts for the nematode, it does not reproduce or survive on broadleaf crops or bare soil. Rotations had not been studied for that purpose in eastern Oregon. Dr. Smiley selected a commercial winter wheat-cultivated fallow field near La Grande on which to conduct a rotation experiment that began during the fall of 1985. The field was highly-infested with the cereal cyst nematode and several species of root-infecting fungi. Discovery of the nematode and a declining yield of winter wheat in the field caused Mr. Cuthbert to plant a perennial seed crop of Kentucky bluegrass around the rotation experiment in the spring of 1988. The field and its rotation experiment were therefore sprinkler irrigated to meet the needs of the surrounding crop of Kentucky bluegrass.

The 5-year experiment examined 11 rotations which were replicated four times in 16 × 100 foot plots. All tillage, planting, harvesting and other crop maintenance was performed by Dr. Smiley, using equipment from the Pendleton Station. Plant foliage and root samples were collected up to three times each year to evaluate plant growth and development, and to quantify all disease symptoms on roots and foliage. Other diseases commonly encountered included eyespot (strawbreaker foot rot), common root rot, take-all, Pythium root rot, and Rhizoctonia root rot. Measurements of plants included height, weight, development stage, tillers per plant, and number of roots intersecting horizontal planes 1- or 2-in below the seed. Soil samples were also collected each year and sent to the Plant Nematode Diagnostic Laboratory at Corvallis, which counted the numbers of nematode. Grain yield and test weight was measured by threshing the 44 plots. During the final year, in 1992, when all rotations were planted uniformly to winter wheat, half of each wheat plot was treated by applying the nematode aldicarb. The aldicarb-treated and the untreated control strips were harvested separately.

Yield of annual winter wheat was always 40 to 60 percent less than wheat alternated with fallow or any other crop, except the alfalfa contaminated with grass weeds. Wheat yielded equally following 1- or 2-year breaks from wheat. Effective breaks included summer fallow, dry pea, and weed-free alfalfa. Throughout the experiment, the cereal cyst nematode was the most important individual constraint to yield. Combined damage from the nematode and take-all caused highest overall yield loss during one year, and the nematode plus Pythium root rot had the greatest negative effect on the number of roots. Disease complexes were therefore recognized as being important in that field. During the fifth year, on the half of the wheat plots treated with aldicarb, root damage by the cereal cyst nematode was decreased but damage by Rhizoctonia root rot and Pythium root rot were increased, resulting in no improvement in wheat yield or test weight.

Crops[a], fallow, tillage and weed control in the rotation on the Cuthbert Farm

	Year of harvest				
Treatment	1988	1989	1990	1991	1992
1[b]	wheat	wheat	wheat	wheat	wheat
2[c]	wheat	wheat	wheat	wheat	wheat
3	wheat	fallow	wheat	fallow	wheat
4	fallow	wheat	fallow	fallow	wheat
5	fallow	wheat	barley	fallow	wheat
6	wheat	pea	wheat	pea	wheat
7	wheat	wheat	pea	pea	wheat
8	mustard	wheat	fallow	mustard	wheat
9[d]	wheat	alfalfa	alfalfa	alfalfa	wheat
10[e]	wheat	alfalfa	alfalfa	alfalfa	wheat
11	KB grass	KB grass	KB grass	KB grass	wheat

[a] Crops were winter wheat, spring barley, yellow mustard, dry pea, alfalfa, and Kentucky bluegrass. Tillage was performed on all treatments except #2, using a moldboard plow, disk, and spring-tooth harrow. Weed-free summer fallow was maintained with a rod-weeder. In the final year, 1992, plots were split by applying an unregistered nematicide (aldicarb) to one 8-foot strip and leaving the remaining 8-foot strip untreated.

[b] Soil was plowed and disked before planting winter wheat annually (conventional tillage).

[c] Stubble was removed by burning and the soil surface shallowly mixed by disk or skew treader before planting winter wheat annually (minimum-till).

[d] Alfalfa was continually rogued to eliminate grass weeds and volunteer cereals.

[e] Alfalfa was moderately contaminated by volunteer wheat, downy brome and wild oats, and no effort was made to control those weeds.

Curtis Hennings Farm (1996-2007)

Winter wheat production in the intermediate to low rainfall areas has continued to rely upon a winter wheat-fallow rotation to provide sufficient soil moisture for an economically-viable wheat crop. This rotation continues to be the most profitable and reliable from year to year. Nevertheless, especially with cultivated fallow, that production system has often left the soil surface open to wind and water erosion, and has been subject to many problems with weeds and diseases. The advent of no-till farming was increasing in the region but it was anticipated that the no-till system would create a new suite of weed and disease problems. That possibility needed to be examined before more farmers made the transition from cultivated to no-till agriculture. Computer models estimated that no-till spring crops could reduce the susceptibility of soil to erosion by 95 percent in low-rainfall regions.

Dr. Frank Young, USDA-ARS at Pullman, WA, conducted a 12-year experiment with alternative spring cropping systems at the Curtis Hennings Farm, 13 miles east south-east of the Dryland Research Station at Lind, WA, where mean annual precipitation is 11.5 inches. The research team included 11 disciplines from five agencies in three states; a farmer, agronomist, weed scientist, plant pathologist, entomologist, soil chemist, soil microbiologist, wheat breeder, barley breeder, soil physicist, and agricultural economist. Dr. Richard Smiley, from the Pendleton Station, was the project's plant pathologist. The experiment was conducted in three phases; Phase I (1995–2000), Phase II (2000–2003), and Phase III (2004–2007).

The goal of Phase I was to determine if planting spring crops could protect the soil while also increasing farm profitability by reducing losses from winter annual weeds and root diseases. Four crop rotation systems were established during the fall of 1995. The rotations were duplicated by being established on two adjacent fields that were in opposite phases of the rotation. The experimental rotations were:

1) Soft white winter wheat-cultivated fallow (traditional system in the region)
2) Soft white spring wheat-chemical fallow (no-till)
3) Annual hard red spring wheat (no-till)
4) Hard red spring wheat rotated with spring barley (no-till)

Each rotation in Phase I was replicated four times and the duplicated plots allowed each portion of each rotation to be studied every year, for a total of 32 plots that measured 30 × 500 feet. Standard farm equipment, fertilizers and rates, seed treatments, and herbicides were used for all management operations.

Rhizoctonia root rot patches in spring barley at the Hennings Farm

By the end of five years, in 2000, crops had been harvested five times from each crop in each rotation, and 10 times from the annual hard-red spring wheat. Weed and disease diversity and intensity were assessed twice each year. Weed density was lower in the spring crop systems than in the winter wheat-cultivated fallow. Weed populations in no-till rotations declined because of late-winter herbicide control of winter-annual weeds, in-crop herbicide control of dicot weeds, and postharvest herbicide applications to control Russian thistle. Patches of stunted or bare soil caused by Rhizoctonia root rot were commonly observed in barley (see Chapter 20). That disease was the primary yield-limiting disease during Phase I of the rotation experiment (Sullivan et al. 2013).

The experiment was modified for Phase II. The goal was to eliminate barley from the rotation and to examine, over four years, the production of no-till facultative wheat which, when compared to true winter wheats, have a shorter vernalization period, earlier initiation of growth and flowering, but less tolerance of freezing during winter. The 32 plots from Phase I were divided to make 64 plots that measured 30 × 250 feet. The Phase II treatments were:

1) Soft white winter wheat-reduced tillage fallow
2) Facultative soft white winter wheat-chemical fallow (no-till)
3) Facultative soft white winter wheat rotated with soft white spring wheat (no-till)

During the four years of Phase II, spring soil water content was greater for chemical fallow compared with reduced tillage fallow. In the fall, the soil water content in the first two feet of the soil profile was less for chemical fallow than for reduced-tillage fallow. Winter wheat-reduced tillage fallow and facultative winter wheat-chemical fallow were more profitable and more productive than facultative winter wheat-spring wheat. The winter wheat-reduced tillage fallow was far more productive than either of the facultative winter wheat rotations. The facultative winter wheat-spring wheat rotation produced lower yields that were more susceptible to fluctuations in crop-year precipitation, contained more weeds, cost more to produce, and was less profitable than the other rotations. The facultative wheat-chemical fallow rotation was less variable than the winter wheat-reduced tillage fallow but net returns over total cost were consistently negative for facultative wheat-chemical fallow. It was concluded that even though facultative winter wheat-chemical fallow yielded and earned less than winter wheat-reduced tillage fallow, the facultative wheat-chemical fallow rotation may be a viable conservation system with cost sharing by government incentives. The advantages of facultative winter wheat-chemical fallow were fourfold: (1) spread-out fall planting and summer harvesting operations, (2) opportunities to control problematic winter-annual weeds, (3) better competition with summer annual weeds than spring wheat, and (4) a late planting date that does not rely on seed-zone soil water like true winter wheat.

In 2003, the experiment transitioned into Phase III, which contained four rotation systems that included two crop rotations per rotation system. Three rotations of Phase III were those described for Phase II. Within each rotation, each crop or fallow treatment was present every year, except where the facultative wheat suffered winter kill. The best-known management practices were used, using commercial-size field equipment. Plant biomass and grain yields were measured, and weeds, diseases and insects were monitored.

The overall performance of the wheat–fallow systems were more productive economically and agronomically than the annual crop rotation. The winter wheat-reduced tillage fallow was again the most profitable by a wide margin. The annual facultative wheat-spring wheat rotation produced lower yields that were more vulnerable to fluctuations in crop year precipitation, contained more weeds, cost more to produce, and provided the lowest net profitability compared with rotations containing fallow. The facultative wheat-chemical fallow was less profitable than the winter wheat-reduced tillage fallow by an average or more than $31 per acre. Chemical fallow cost more to maintain than reduced tillage fallow. Nonetheless, yields of facultative wheat were excellent during three of the four years.

Downy brome and Russian thistle were the most pervasive weed species. Populations of downy brome were often 90 percent higher in the facultative wheat-spring wheat rotation than in either winter wheat or in facultative wheat following chemical fallow. Facultative wheat also had less root disease than winter wheat, due to the difference in planting date for these practices.

Even though winter wheat-reduced tillage fallow was the most profitable conservation practice, the agronomic advantages of facultative wheat-chemical fallow were numerous. These advantages included:

1) reduced soil compaction compared to planting into wet soils in the spring,
2) well spread-out fall planting and harvesting operations,
3) opportunities to control problematic winter-annual weeds,
4) better competition with summer-annual weeds compared to spring wheat, and
5) a late planting date that did not rely on seed-zone soil water like winter wheat.

It was concluded that facultative wheat could have been a viable conservation system, depending upon cost sharing and other considerations, and that additional research was needed to improve facultative wheat varieties and production strategies, and to identify alternative crops compatible with chemical fallow.

William Jepsen Farm (1999-2008)

The Monsanto Company and cooperating farmers conducted several cropping systems demonstrations in the low-rainfall region during the early 2000s. One demonstration was the farm of Mr. Bill Jepsen, near Heppner, OR. The 'Center of Sustainability' demonstration was established to compare winter wheat with spring crops. During 2003, the demonstration was incorporated into the crop rotation experiment that was being established at the Sherman Station at that time Treatments included nine cropping systems that were similar to those described earlier for the Sherman Station ('since 2004'). Mr. Jepsen managed the crops and harvests, and other data was collected by Drs. Stephen Machado (agronomist), Dan Ball (weed scientist) and Richard Smiley (plant pathologist).

The Center of Sustainability site was important because it received crop-year precipitation similar to that at the Sherman Station, but it had much shallower soil. The treatments at the Jepsen Farm were not replicated but they were very large (80 × 900 feet), which made it possible to split the plots to make measurements in two or more pseudo replications.

Data was collected as was described for the experiment at the Sherman Station. The 4-year average grain yields were highest for winter wheat rotated with fallow, and for spring barley. On an annualized basis, annual spring barley produced the highest grain yields. There were no yield differences between annual winter wheat and annualized yields of winter wheat after either chemical fallow or the traditional trashy (high surface residue) fallow. Averaged yield was higher for annual hard red spring wheat than for annual soft white spring wheat. As at the Hennings Farm, Rhizoctonia root rot was the primary yield-limiting disease for barley. Patches of stunted or bare soil were observed in some plots of wheat and barley during this experiment.

Treatments in the Center of Sustainability demonstration at the Jepsen Farm.

Rotation	Treatment	Rotation description	Tillage*
1	1 & 2	Winter wheat-conventional trashy fallow	CT
2	3 & 4	Winter wheat-chemical fallow	DS
3	5	Annual soft white winter wheat	DS
4	6	Annual spring wheat	DS
5	7	Annual spring barley	DS
6	8	Annual hard red spring wheat	DS
7	9, 10 & 11	Winter wheat-spring mustard-chem. fallow	DS
8	12, 13 & 14	Winter wheat-spring barley-spring mustard	DS
9	15 & 16	Flex crops**	DS

*CT = conventional tillage using high-residue 'trashy' fallow; DS = direct seeded (no-till).

** Two sequences of direct-seed flexible management treatments included crops and sequences based upon real-time decisions regarding current market prices and current and expected soil moisture. Crops in these flex-crop rotations included winter wheat, spring wheat, spring barley, spring canola, and yellow mustard.

Grain yield (bushels/acre) of winter wheat, spring wheat, and spring barley at the Center of Sustainability* near Heppner, Morrow County, Oregon.

	Annual cropping				Two-year rotation		Sept-June precip. (inches)
Crop year	SB	SWSW	HRSW	SWWW	SWWW/CuF	SWWW.ChF	
2004-05	42	16	23	25	68	71	9.4
2005-06	52	29	28	34	47	56	14.5
2006-07	47	29	25	33	62	56	12.3
2007-08	21	0	16	19	36	36	7.8
Mean	41	19	23	28	53	55	11
Annualized	41	19	23	28	27	28	

*Annual crops were each produced without tillage; SB = spring barley, SWSW = soft white spring wheat, HRSW = hard red spring wheat, SWWW = soft white winter wheat, CuF = cultivated (trashy, or high surface residue) fallow, ChF = chemical fallow (no-till)

Vertical distribution of root-lesion nematodes (*Pratylenchus neglectus*/lb of soil) at the Center of Sustainability* during the 2004-2005 crop year.

Profile depth (in)	SWWW-CuF	CuF-SWWW	SWWW-ChF	SB	SWSW	HRSW
0-6	128	1,778	330	79	366	676
6-12	389	1,512	681	238	789	715
12-18	679	1,323	448	243	641	145
18-24	401	168	995	137	842	8
24-36	0	241	188	0	9	0
36-48	0	7	1	0	1	0
mean: 0-12	259	1,645	506	159	578	696
mean: 0-18	399	1,538	486	187	599	512
mean: 0-24	399	1,195	614	174	660	386

*Annual crops were each produced without tillage; SB = spring barley, SWSW = soft white spring wheat, HRSW = hard red spring wheat, SWWW = soft white winter wheat, CuF = cultivated (trashy, or high surface residue) fallow, ChF = chemical fallow (no-till). For rotations, the first mentioned treatment was the phase sampled for this evaluation; for example CuF/SWWW was sampled during the fallow phase.

Five pairs of soil samples were collected from each of six plots by using a Giddings hydraulic soil sampler during the 2005 crop year. The 10 cores were separated into depth intervals of 0-6, 6-12, 12-18, 18-24, 24-36, and 36-48 inches, and numbers of root-lesion nematodes were averaged for each depth interval. Some treatments had the highest nematode populations in the upper foot of soil and other treatments had the most nematodes in the second foot. Numbers were highest in soft white winter wheat produced in cultivated fallow. Numbers were also high in annual spring wheat, and were lowest in annual spring barley. When wheat roots were treated with a biological stain, it became clear that some roots were entirely packed with nematodes, and that these nematodes were contributing to an overall reduction in crop yield.

Sampling of soil from nearby yellow mustard fields revealed higher populations of root-lesion nematodes than in nearby wheat fields. Numbers in barley fields were at least 75 percent lower than in spring wheat.

Leon and Dorothy Reese Farm (2013-2018)

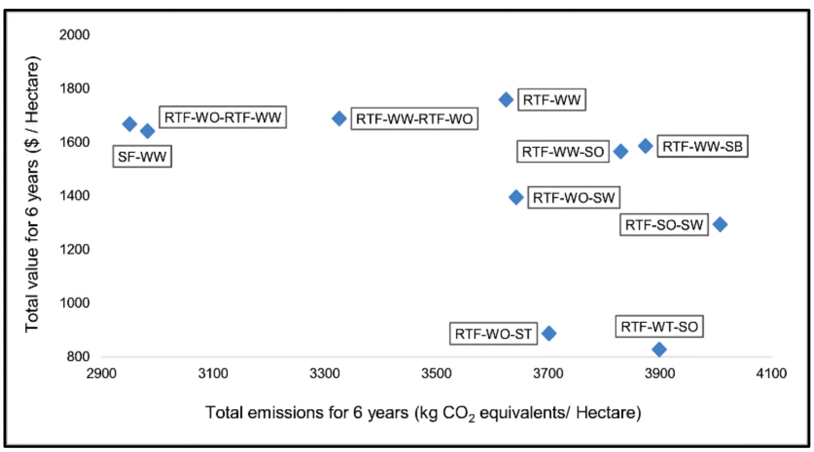
This study investigated the integration of bioenergy oilseeds into food grain cropping under low precipitation (11.4 inches), non-irrigated conditions. The experimental site was located about 10 miles west of Pendleton, on the Leon and Dorothy Reese Farm. The objectives included: 1) evaluate the yield performance of cereal-based rotations that include oilseeds, 2) determine whether wheat-oilseed rotations provide belowground benefits, 3) determine if oilseeds promote overwinter infiltration and soil water storage, 4) ascertain the competitiveness of cropping intensification on weeds, and 5) evaluate the carbon and energy footprints of these rotations.

The experiment consisted of nine crop rotations to evaluate crop intensification and biofuel production using a spring oilseed (carinata) or a winter oilseed (canola) in rotation with winter wheat or spring cereals. All except Treatment #1 used reduced-tillage fallow (RTF).

1. Cultivated summer fallow rotated with winter wheat; coded SF-WW
2. Reduced-tillage fallow rotated with winter wheat; RTF-WW
3. Reduced-tillage fallow / winter wheat / spring barley; RTF-WW-SB
4. Reduced-tillage fallow / winter wheat / spring carinata; RTF-WW-SO
5. Reduced-tillage fallow / winter canola / spring wheat; RTF-WO-SW
6. Reduced-tillage fallow / spring carinata / spring wheat; RTF-SO-SW
7. Reduced-tillage fallow / winter canola / spring triticale; RTF-WO-ST
8. Reduced-tillage fallow / winter triticale / spring carinata; RTF-WT-SO
9. Reduced-tillage fallow / winter wheat / RTF / winter canola; RTF-WW-RTF-WO

Greenhouse gas (GHG) emissions were measured over two years. Inputs were monitored for fertilizers, seed, pesticides, and fuel. The carbon footprint and cumulative energy consumption were determined for each treatment (Ankathi et al., 2018). Highest yields were attained when cereal or oilseed crops were planted following reduced-tillage fallow. Winter wheat yields did not diminish for more intensive 3-year rotations compared to conventional 2-year rotations with or without oilseed crops. Greenhouse gas emissions for winter wheat (0.3-0.4 pounds CO_2/pound of winter wheat) were always in the lower part of the range detected throughout the U.S. (0.3-0.6 pounds). The lowest emission from an oilseed was 0.7 pounds CO_2/pound of grain for winter canola following reduced-tillage fallow. Fossil energy invested for bioenergy return for oilseed oil production showed net positive returns of nearly a factor of two to four across all spring and winter crops. From a trade-off plot of GHG emissions versus total sales per acre over six years, the winter wheat-summer fallow and winter wheat-reduced tillage fallow were shown to be the most promising with low emissions and high sales. This study demonstrated that bioenergy oilseed cultivation can be incorporated into dryland food production systems without diminishing per area food grain yields. Also, economic performance could be enhanced with higher yielding, drought tolerant oilseed varieties that would be more readily adopted by farmers.

Gas-collection chambers for measuring emissions of carbon dioxide, nitrous oxide and methane



Comparison of sales value and total gas emissions for nine dryland crop rotations over six years at the Reese Farm; values are in metric units

References:

Annual Reports from the Sherman and Pendleton Stations (Appendices 5 and 6)

Letters sent to or from the Station Superintendents

Ankathi, S. K., D.S. Long, H. T. Gollany, P. Prajesh, and D. Shonnard. 2018. Life cycle assessments of oilseed crops produced in rotation with dryland cereals in the inland Pacific Northwest. International Journal of Life Cycle Assessment. 24:627-641. Correction at https://doi.org/10.1007/s11367-018-1498-9.

Awale, R., S. Machado, and K. Rhinhart. 2018. Soil carbon, nitrogen, pH, and crop yields in winter wheat-spring pea systems. Agronomy Journal 110:1523-1531.

Brown, W. G., and M. M. Oveson. 1960. Profitability of field crop rotations in Umatilla County. Oregon Agricultural Experiment Station Circular 573. 9 pages.

Jones, J.S., and W.W. Yates. 1924. The problem of soil organic matter and nitrogen in dry-land agriculture. Agronomy Journal 16:721-731.

Seavert, C., S. Macnab, K. Sharp, and S. Petrie. 2012. Enterprise budget for wheat (winter) following fallow, direct seed, less than 12-inch precipitation zone, north central zone. Oregon State University Extension Service Bulletin AEB 0034. 4 pages.

Smiley, R. W., and S. Machado. 2009. *Pratylenchus neglectus* reduces yield of winter wheat in dryland cropping systems. Plant Disease 93:263-271.

Smiley, R. W., S. Machado, J. A. Gourlie, L. C. Pritchett, G. P. Yan, and E. E. Jacobsen. 2013a. Effects of crop rotation and tillage on *Pratylenchus* spp. in the semiarid Pacific Northwest United States. Plant Disease 97:537-546.

Smiley, R. W., S. Machado, J. A. Gourlie, L. C. Pritchett, G. P. Yan, and E. E. Jacobsen. 2013b. Influence of semi-arid cropping systems on root diseases and inoculum density of soilborne pathogens. Plant Disease 97:547-555.

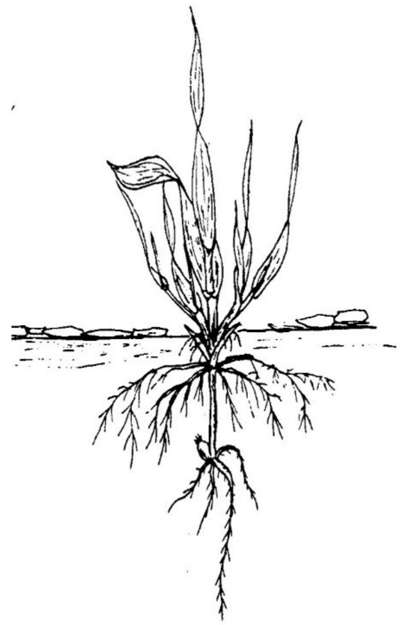
Stephens, D. E. 1924. Dry-Farm Crop Rotation Experiments at Moro, Oregon. Agricultural Experiment Station Bulletin 209, Oregon Agricultural College and USDA Office of Cereal Investigations, Corvallis. 45 pages.

Stephens, D. E., and C. E. Hill. 1917. Dry Farming Investigations at the Sherman County Branch Experiment Station. Agricultural Experiment Station Bulletin 144, Oregon Agricultural College, Corvallis. 47 pages.

Stephens, D. E., and G. R. Hyslop. 1922. Wheat Growing after Fallow in Eastern Oregon. Oregon Agricultural College Experiment Station Bulletin 190. 35 pages.

Sullivan, L. S., F. L. Young, R. W. Smiley, and J. R. Alldredge. 2013. Weed and disease incidence in no-till facultative wheat in the Pacific Northwest, USA. Crop Protection 53:132-138.

Nairn, J. 1956. Evaluation of Dry Land Crop Rotation Experiments at Sherman Branch Experiment Station, Oregon. Oregon Agricultural Experiment Station Miscellaneous Paper No. 23. 19 pages.



Chapter 13 - Tillage and Crop Residue Management

Improvement of tillage and residue-management practices has always been a principal mission for both of Oregon's dryland crop research stations. An immediate and essential goal of both stations was to produce and report unbiased scientific comparisons of tillage systems for their effects on stabilizing and preserving the soil resource, on wheat yields and profitability, and on effects on soil water and soil organic matter. Tillage and residue management are topics that are so completely dependent upon one another that they are discussed together in this chapter. However, an effort has been made to discuss in other chapters the effects of tillage and residue management on soil fertility, soil organic matter, water infiltration and maintenance, and others. More than 40 different tillage and residue management experiments have been conducted at the Sherman and Pendleton Stations.

When the stations were established, all farmers tilled all land between crops. The farmers faced decisions of three main types. They first had to determine how they could do the best job of preparing a field and its standing residue for the plowing operation. This was considered a pre-plowing operation, which often times came to a decision to either burn the stubble or to do something to make sure that the plow would be effective and efficient. The decision needed to include consideration of achieving the greatest capture of moisture during the first winter following harvest of the previous crop. It also needed to consider what techniques could be used to control weeds and volunteer wheat, each of which could deplete soil moisture and nutrients during the fallow season.

When it came time to plow, there were questions about the best method, best depth, and best timing. Each of those factors affect conservation of moisture and, before the era of commercial fertilizers, the mineralization of nitrogen that was needed for good yields in the following crop. After plowing, farmers needed to know which methods of cultivation conserved the moisture and nitrates in the soil profile, all while controlling weeds during the fallow and leaving a suitable seedbed for the crop to be planted. It was also clear that some methods opened the soil to erosion from wind and water, which needed to be avoided. Finally, all of those tillage considerations needed to be balanced by determinations of whether or not the cost of each tillage operation would offset or exceeded by an increase in productivity of the crop.

The burning of wheat straw in the spring, before plowing, was at one time a very common practice in the wheat producing areas of the Columbia Plateau. All of the agricultural agencies began carrying on a vigorous educational program to curtail that practice because it reduced organic matter in soil, which reduced soil tilth and penetration of water. On the other hand, without an alternative way to successfully manage the amount of straw being produced, particularly in highly productive areas that received higher amounts of rainfall, the farmers found that burning was the only way to get their crop planted with the tillage equipment and seed drills that were available during the early years.

Tillage and residue management experiments were therefore among the first to be established when each of the dryland stations began operating. In 1911, at Moro, the design of all experiments was a joint exercise of W. M. Jardine (USDA-BPI, Washington, D.C.) and H. C. Scudder (OAES, and the first-but-temporary Superintendent of the Sherman Station).

Soil conservation was at the forefront of thoughts and activities at the research stations. Many experiments were therefore directed by or involved strong collaborations with employees of the USDA-SCS. The relationships between the Station personnel and the SCS have been deeply inter-related throughout the history of these stations. Examples were illustrated in Chapter 8. Also, in 1938, Mr. Joseph Belanger was appointed by the SCS and the USDA-BPI to work on stubble-mulch summer fallow problems in eastern Oregon. He was initially stationed at the Sherman Station. One year later, he was transferred to the Pendleton Station, where he served until 1943.

The need for the close relationships between the stations and the SCS could not be better described than was stated in the Sherman Station's 1965 Annual Report. An excerpt of that statement was the following. "*The 1964-65 year has gone down in the record books as a year to be long remembered, from the standpoint of adverse weather conditions and poor crops. Due to lack of soil moisture, seeding was delayed and in some areas many acres were not seeded. December had 6.1 inches of precipitation, which was 4.5 above the 30-year average, and the highest since weather recording started at the Sherman Experiment Station in 1911. On December 22nd and 23rd over two inches of rain fell. Because of frozen ground, and almost a foot of snow at the time, heavy run-off occurred and millions of dollars in damage resulted. Loss of topsoil amounted to many thousands of tons and gully erosion was said to be the worst in the history of the Mid-Columbia area. Thousands of acres of fall-seeded grain were lost due to washing* *out, smothering and winter-killing. This necessitated reseeding in the spring and lack of moisture resulted in extremely poor growing conditions. Nurseries at the Station were either destroyed or had low yields. This was the first time in the history of the station that such a complete loss has occurred.*"

By the mid-1950s the scientists had become confident that the results of early tillage experiments were accurate and the time had come for them to be terminated. Some of the experiments had been started in 1912 at the Sherman Station and in 1931 at the Pendleton Station. The 1954 Annual Report from the Sherman Station stated that "*As soon as it is possible to evaluate the possible soil changes* [soil structure and organic matter] *and to ascertain that there is no need for continuing the experiments, they shall be revised and current techniques employed in designing and laying out new plots*." Therefore, the time of tillage experiment '*is being revised to eliminate the date of plowing component as all plowing is now done by farmers as early as possible* [in the spring]… *and the Station has proven its point that delayed plowing is costly. The Station is credited with having early acceptance of this recommendation by farmers of the area*."

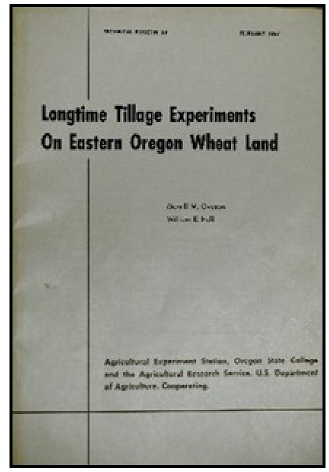
Most tillage and crop residue experiments established during the first four decades at both dryland experiment stations were therefore terminated or greatly altered after the harvest of 1955. The decision for termination was reached at the Soil and Water Conservation Research Branch Planning Conference at Oregon State College in early February, 1955. The two station superintendents, Merrill M. Oveson and William (Bill) E. Hall summarized the data from this research and published it in a bulletin (Oveson and Hall, 1957).

While the tillage and residue management experiments at the Sherman Station continued at a lower level of intensity after 1954, nearly all of the on-station and off-station field experiments were terminated when the station ran into serious financial troubles in 1964. The Station's operating expenses had exceeded the Station's budget for a number of years, and reserve funds that had been used to prop up the station had been zeroed out by 1964. That crisis was confounded when voters rejected the 1964 State Legislative Budget, which resulted in a further reduction in the Station's funding. The critical shortage of operating funds led to an abandonment of most experiments. The farm foreman at the Sherman Station resigned and, shortly thereafter, Bill Hall, the Superintendent, decided it would be an opportune time to take a sabbatical leave to earn a Ph.D. degree at the University of Michigan. He never returned.

Summaries of tillage and residue management studies conducted at both of the dryland stations had been summarized in extension publications contained a brief description of experiments and statements as to why those experiments were informative and meaningful. Examples of those bulletins included *Longtime Tillage Experiments on Eastern Oregon Land* (by Oveson and Hall, 1957), *Conservation Practices on Wheat Lands of the Pacific Northwest* (Stephens, 1944), *Methods of Disposal of Crop Residues for Growing Wheat after Fallow in Eastern Oregon* (Stephens et al., 1941), and *Stubble Mulching in the Northwest* (Horning and Oveson, 1962b). These bulletins were user-friendly and well-illustrated to describe and show farmers how to effectively perform each tillage operation for establishing an effective high-residue fallow without encountering time-consuming problems such as plugging the equipment with too much straw or soil.

Tillage Experiments

1. Starting in 1911, many tillage and residue management systems that included as many as 48 different methods were examined over long time intervals
2. All treatments were evaluated by the cost per acre relative to subsequent wheat yields
3. The stubble-mulch fallow system with a rod weeder and deep-furrow drill was developed and refined
4. Early spring plowing dates produced 3.3 bushels more wheat than plowing in the fall or later in spring
5. Wheat yields were related directly to the amount of soil water stored
6. Comparisons were made of many different primary tillage implements; including equipment design and the timing and depth of tillage
7. Harrowing wheat was commonly practiced at first, but was shown to reduce wheat yield and profit
8. The management of summer fallow was examined thoroughly; from no tillage to plowing, disking and up to 10 passes with a rod weeder
9. High-residue fallow was frequently heavily contaminated with downy brome, even when the weed wasn't allowed to go to seed in the trials
10. Up to 22 years of adding strawy manure or pea straw did not improve wheat yields over the more simple retention of straw from the previous wheat crop
11. Chemical fallow was first examined in a trial from 1960 to 1969



In 1974, ten years after most tillage experiments had been terminated at the Sherman Station, the OAES appointed members of the Sherman Station Advisory Committee (Paulen Kaseberg, Charles Burnet, Vernon Miller, Bob Holmes, Paul Alley, Giles French, Willis Nartz, Gordon Cook, James Johnson, Larry Snyder, John Clausen, Ken Smouse, and Bill Hulse) to "*… advise us on the changes to be made at the Station in reshaping the physical layout of fields, etc. for future experimental work. Dr. Floyd Bolton has been assigned responsibility to supervise this aspect of the program. ... We are optimistic that the changes we are making at Moro will benefit the research program there*." The OAES then informed scientists at Pendleton and Corvallis that Bolton was now in charge of making changes and administering all field experiments at the Sherman Station, including the SCS grass plantings at the station, and an agreement between the station and the Sherman County Soil and Water Conservation District. That agreement was for developing and carrying out a formal conservation plan. The SCS had prepared a detailed mapping of the soils that showed eight soil types on the station. Seven of the soils were variants of Walla Walla silt loams and, in three drainages, there was a Starbuck very stony silt loam. The conservation plan called for installation, over time, 3,500 feet of gradient terracing, two silt dams, repair of grass waterways, rotational cattle grazing on 31 acres of grassland, and use of trashy fallow on the 170 acres of crop production land. On June 1, 1979, Dr. Steve Lund, Superintendent of the Columbia Basin Agricultural Research Center, submitted to the OAES a summary of conservation work that had been accomplished and work still planned at the Sherman Station. The summary had been prepared by Drs. Floyd Bolton and Jim Vomocil, in collaboration with Mr. Del Smith, the farm manager at the Sherman Station.


Dr. Floyd Bolton

For two decades, starting in 1974, Dr. Floyd Bolton and his students at Corvallis conducted extensive research at the Sherman Station. They examined topics relating to soil fertility, soil water, soil temperature, and 'strip-till' planting systems for producing wheat without tillage. Bolton's research at Moro resulted in the publication of seven technical journal papers and 15 semi-technical papers. His planting systems experiments are summarized in this chapter.

Some of the 40-plus experiments at the stations were of short duration (2 to 5 years) but others continued for at least four or five decades. One tillage experiment established at the Pendleton Station during 1940 is still being conducted nearly eight decades later. Experiments were often duplicated at Moro and Pendleton to examine tillage and residue management practices under two moisture regimes; 11 and 16 inches annually at Moro and Pendleton, respectively. Some of the experiments were large and complex; one winter wheat experiment at Moro compared 48 different tillage and residue management methods on 14 acres of land. Since there were so many of these experiments at the stations, they are discussed only in general terms in this chapter.

Until 1974, detailed results of all experiments were reported in the Annual Reports from each station. Some results were also published in technical journals, particularly during the past four decades. The intent here is to communicate the types of issues that were addressed and some of the more important findings.

Methods of Primary Tillage

Disking vs plowing

Early farmers sometimes disked the stubble during the fall to encourage partial decomposition of the straw before the soil was plowed during the spring. At Moro, over a 42-year period, winter wheat yielded an average of 0.7 bushels/acre less when land was disked during the fall than when stubble was left standing during the winter. At Pendleton, over 22 years, that average yield advantage was 2.7 bushels/acre for land that was not disked in the fall. When land was not tilled during the fall but was disked during early spring to break the straw into shorter lengths before it was plowed, the pre-disking operation depressed yields by at least 1.5 bushels/acre at both dryland research stations.

Lister plow vs moldboard plow

At Moro, stubble-mulch fallow prepared by a lister plow gave average yields that were lower than when the primary tillage was done with a standard moldboard plow that left no residue on the surface; 25.8 vs 28.4 bushels/acre. The lister plow treatment was therefore eliminated from experiments after seven years of testing. A lister plow differed from the more common form of moldboard plow in that it had two surfaces, one on each side of the beam for shedding and throwing aside the soil in both directions.

Burning vs turning the stubble under

It was once common for farmers to burn the stubble in an attempt to make it easier to cultivate the soil and to possibly kill some of the weed seeds that had fallen to the soil surface before or during harvest. Some farmers also felt that the burning treatment improved yields of winter wheat. However, it was also widely recognized that stubble burning increased to risk for soil erosion. An experiment at Moro was conducted over a 31-year period (1913 to 1944) to determine if burning had a long-term influence on yield of winter wheat. During the first decade of the experiment, when straw was burned rather than cultivated into the soil, the burning treatment produced yields that were about 2 bushels/acre less than when the straw was retained. That difference then slowly diminished until yields in the burn treatment surpassed those of the utilized treatment during the 14th year, and then remained superior during the remaining half of the study period.

Another burn vs. no-burn experiment was established at Moro during 1938 and continued until 1954. That experiment incorporated a depth-of-plowing variable and a date-of-plowing variable. Yields were consistently higher when stubble was burned for both the shallow and deep plowing depth treatments. During the first decade of the experiment the average yield advantage when stubble was burned was 3 bushels/acre for the deep plowing and 4 bushels/acre for the shallow plowing treatment. Those differences diminished slightly over the next decade. When the experiment was terminated in 1954, the 18-year mean yields showed that the stubble burning treatment yielded 2 to 3 bushels/acre more than the stubble incorporation treatment. The benefit from burning rather than incorporating the straw was from 3.4 bushels/acre on late, shallow plowed ground to 1.5 bushels/acre on ground plowed early and deeply. The differences varied each year, but there were some years when the advantage due to burning exceeded 10 bushels/acre. While more productive, it was also observed that fields in the area that were frequently burned were more erosive than those on which the stubble had been worked into the soil. By the late 1940s, under heavy influence by most agricultural agencies, and because of personal experiences with erosion in burned fields, most farmers had discontinued the practice of burning the stubble in drier areas of the Columbia Plateau, such as in Sherman County.

However, a different pattern occurred in a similar experiment at Pendleton, where the burn treatment consistently outperformed the straw-utilized treatment during the first decade of a 17-year experiment. Yields were virtually equal during the last half of the study period. Nevertheless, during the early 1950s, because of additional fertilizer use, farmers found that they produced so much straw during wetter years that it was almost impossible to manage the stubble with current equipment. After years with high yields there was an inordinately high percentage of fields that were burned. The 1954 Annual Report of the Pendleton Station cautioned that "*If the use of nitrogen fertilizers are going to tend to produce straw in excess of that which farmers can conveniently handle, the fertility problem is going to become more acute than if the fertilizers were not used. Evidence of erosion in the area bears this out as land is becoming more erodible. It is also noticeable that land on which the straw has been consistently burned is eroding more seriously than land where the straw has been incorporated back into the soil*." In higher rainfall areas of western Umatilla County, the burning of stubble continues to be practiced on some fields even at the present time.

Depth of plowing

A depth of plowing experiment with a straw-burning treatment was established at Moro in 1913 and continued until 1954. The 41-year average wheat yield was essentially the same for plots had been plowed deeply (10 inch) or shallowly (5 inch); deep plowing yielded an average of 0.6 bushels/acre more than shallow plowing; 23.7 and 23.1 bushels/acre, respectively. A nearby experiment established that shallow plowing required fewer and smaller horses, resulting in greater overall profitability due to very little difference in grain yield between plowing depths.

In a similar date and depth of plowing experiment at Pendleton, the yield advantage from deep plowing at 9-inch depth over shallow plowing at 5-inch depth averaged 1.1 bushels/acre for each of the four plowing dates over a 23-year period from 1931 until 1954.

Time of plowing

During the late 1910s, practically all of the summer fallow in the Columbia Basin region was being plowed during the spring before winter wheat was planted during the fall. Experiments at the Sherman Station quickly established and confirmed the validity of the observation that wheat yields in winter wheat-fallow rotations were indeed improved when plowing was done during early spring, and that yields were higher if the soil was plowed rather than left without tillage. Nevertheless, the experiment continued for another four decades so that results could be evaluated through many years with variable weather conditions. Date-of-plowing experiments were conducted over a 41-year period at Moro and an 23-year period at Pendleton.

At Moro, plowing early (April 1) always yielded more than plowing later (May 1) or very late (June 1). The respective average yields were 27.7, 25.2 and 20.2 bushels/acre. At Pendleton, plowing during early spring (March 15) yielded more than plowing during the fall (October 15) or during mid-spring (April 15) or late spring (May 15). The respective average yields were 38.8, 36.9, 36.6 and 34.5 bushels/acre. There were only a few years in which yields were marginally better for the fall-plowed treatment than the early-spring plowed treatment. Plowing during early spring retained more water throughout the profile compared to fallow prepared during June or the previous fall. The June-plowed ground lost the equivalent of 2.4 inches of rainfall more than the ground plowed a month earlier. The spring-plowed soil that had standing stubble during the winter absorbed the autumn rains more readily than the fall-plowed ground. Some of the advantage from spring plowing was that more nitrification of residue occurred with earlier spring plowing than for latter. More nitrification also occurred with deeper than shallower plowing depths.

At Pendleton, the 23-year (1931-1954) mean wheat yield in the date and depth of plowing experiment showed that plowing during the early spring (March) produced higher yields (39.2 bushels/acre) than plowing during the fall (38.3 bushels/acre) or later in the spring (37.0 bushels/acre in early April, and 35.0 bushels/acre in late April). For each of the plowing dates, deep plowing (8 inches) always yielded about 1.1 bushels/acre more than shallow plowing (5 inches).

Plowing vs disking in the spring

At Moro, over a 39-year interval, land that was plowed rather than disked yielded an average of 1.2 bushels/acre more grain than land that was disked; 22.5 vs 21.3 bushels/acre, respectively. Over 19 years at Pendleton, moldboard plowing provided 3.4 bushels/acre more than double disking (36.2 vs 32.8 bushels/acre) and 4.5 bushels/acre more than one-way disking (36.2 vs 31.7 bushels/acre).

Chisel plow vs moldboard plow

Another experiment at Pendleton established that plots that were moldboard plowed during the early spring yielded a 16-year average of 38.1 bushels/acre, which was greater than plots that had been one-way disked in the fall and spring (34.6 bushels/acre), double disked in the fall and spring (33.5 bushels/acre), or chisel plowed in the fall and double disked in the spring (34.7 bushels/acre). However, it was also shown that during the first decade of the trial at Pendleton, the moldboard plow yielded from 3 to 8 bushels/acre more than the chisel plow treatment, and the yield gap then started to diminish and was eliminated during the last five years of the experiment. The experiment was expanded at least once to evaluate additional variables.

Deep chisel tillage during the fall

A trial was initiated at Moro during 1931 to examine the value of a using a Killefer deep-tillage chisel in September. The chisel was operated at a depth of 20 inches in an attempt to improve moisture penetration and to store more soil water. After chiseling after harvest, the land was either plowed or disked and then left fallow until the following fall. Those treatments were compared to soil that had either been plowed only, or disked only. The chisel had no effect on either moisture content of the soil profile or on yield of winter wheat.

Sweep plow vs moldboard plow

During the mid-1930s, the focus of tillage experiments turned more heavily toward practices that could best conserve soil but also produce the best wheat yields. One experiment at Moro quickly showed that winter wheat planted on bare or 'black fallow' yielded more than wheat on 'protected' stubble-mulch fallow. The 14-year (1938-1951) average wheat yields were 28.5 bushels/acre for black fallow vs 25.5 bushels/acre for sweep tillage. The 'black fallow' was prepared with a moldboard plow equipped with a jointer to bury all stubble. The 'protected' stubble-mulch fallow was prepared with a Dempster sweep plow using 30-inch sweeps that left all of the crop residue on the surface. A rotary rod weeder was used to kill weeds in both tillage systems. All of the protected fallow plots had downy brome (cheatgrass) growing in them even though no cheatgrass was allowed to go to seed in either of the fallows. Downy brome densities were high enough to reduce grain yield in the protected fallow. While the yields were higher on the black fallow, the greater amount of surface residue in protected fallow clearly reduced soil erosion from wind and water. Very early into those investigations, another experiment was established that determined that optimum soil fertility practices could alleviate the yield depression associated with stubble-mulch fallow.

A similar 'trashy fallow' experiment was established at the Pendleton Station in 1931. The experiment was a collaboration between the OAES, the USDA-SCS, and the USDA-BPI. The goal was to determine if they could find a way to minimize yield reductions associated with conservation tillage systems. In 1941, after 10 years, the experiment was modified by terminating a double-disk treatment and replacing it with the moldboard plow and the Noble sweep blade. At the same time, in 1941, they established another set of tillage experiments about a half mile away from the original set. The second experiment included 11 plots, five of which were moldboard plowed either during fall or early spring, two were chisel plowed in the fall and double disked in the spring, two were one-way disked in the spring, and two were double disked in the spring. As in other tillage experiments, by 1955, the average wheat yields were 4- to 5-bushels/acre higher in land that had been moldboard plowed during early spring. Winter wheat yields were lower and nearly equivalent in all other treatments. Yields were comparable when wheat was grown on a full mulch fallow compared to a semi-mulch made with the one-way disk or an offset disk. Rotary subsoiling or disking stubble in the fall gave no advantage over land where stubble was left standing. Addition of phosphorus and sulfur with the nitrogen gave no further increase in wheat yield, compared to nitrogen alone. An additional 20 pounds N/acre was needed to equilibrate the yields of mulch fallow with that of clean moldboard plowed fallow. The introduction of 2,4-D herbicide into the crop management had almost eliminated broadleaf weeds as a yield-influencing factor that was common during earlier years of this experiment. In essence, these experiments also quickly demonstrated that winter wheat was more productive when planted into 'black fallow' than into stubble-mulch fallow.

In 1954, Ted Horning initiated yet another study of methods to handle 7,000-pound/acre straw mulches on the Pendleton Station. He compared a Noble 'V' type sweep blade with roll-over, two-bottom, and two-way moldboard plows. The moldboard plots had variables of the Gooley spring tooth or end-drive Calkins rod weeder. At planting time, five different drills were used to compare deep-furrow, semi-deep furrow, double disk, and shoe openers. Again, lots of photos were displayed in the 1954 Annual Report.

Intensification of studies on stubble-mulch tillage

One of the earliest studies at the Pendleton Station was called a 'trashy fallow' experiment. Established in 1931, it compared fallow prepared by moldboard plowing, double disking, or by 1-way disking. The original purpose was to study methods of preparing the seedbed for continuous cropping. These primary tillage systems were then evaluated by comparing different methods of cultivating the fallow after plowing, by harrowing immediately after plowing and keeping the fallow clean, by harrowing 30 days after plowing and keeping the fallow clean, or by 'minimum cultivation' consisting of a single harrowing after planting and then allowing weedy fallow until rod-weeding just before the weed seeds matured.

Within the first decade it became well established that the trashy fallow practice, which by then had been renamed 'stubble-mulch fallow', greatly reduced soil erosion but also reduced grain yields at both Stations. The trashy fallow left judicious amounts of straw near the soil surface, which made it nearly impossible to maintain the fallow by any tillage equipment other than the rotary rod-weeder. Common implements used on clean fallow, such as the spring tooth harrow or spike tooth harrow, clogged badly in the high-residue fallow. Seed planted during the fall failed to emerge uniformly or fully, and crops on trashy fallow didn't yield as well as those on fallows that were plowed deeply. Farmers could get good seedling emergence only if they planted spring wheat, which was planted after the straw had started to decompose.

High-residue fallow also increased problems with downy brome, created a need for higher nitrogen fertilizer application rates, and created greater complexity with machinery and methods needed to handle the surface residue.

The USDA intensified its effort to curtail soil erosion problems by overcoming the disadvantages of stubble mulching. Joseph Belanger was hired by the SCS in 1939. He was first located at the Sherman Station. Belanger immediately established an experiment to determine the value of nitrogen fertilizer in over-coming the yield depression that was commonly observed between stubble-mulch fallow and land that was inverted with the moldboard plow. The experiment was set up at the Pendleton Station as well as at the Sherman Station. The experiment had three replications of 18 treatments (54 plots) to compare three spring tillage treatments and six rates of nitrogen application. Both the in-crop and fallow phases were produced each year, allowing wheat yield data to be collected each year. The three types of tillage performed on standing stubble during the spring included the moldboard plow, one-way disk, and subsurface sweep, which, at the time of planting, left about 7, 34 and 43 percent, respectively, of the original stubble remaining on the soil surface. The range of nitrogen application treatments was lower at Moro than at Pendleton because of the differences in rainfall and wheat productivity between those locations. The experiment at Pendleton was initially more complex than that at Moro, in that the plow treatments included two depths of operation (5- and 8-inches). At both locations, Belanger measured soil moisture content and nitrate concentration at 1-foot depth intervals to a depth of six feet in the 54 plots. Belanger was transferred to the Pendleton Station in 1940 and he continued to operate experiments at both locations until his departure in 1943.

Belanger's tillage × fertility experiment at Moro, established in 1939, was terminated in 1953. The 13-year average winter wheat yields produced in the plow, disk and sweep tillage treatments were 31.9, 29.1 and 28.2 bushels/acre, respectively. An application 40 pounds of nitrogen/acre produced the maximum grain yield but there were strong variations in the optimum nitrogen rate from year to year. While no cheatgrass was allowed to go to seed in the fallow, there were cheatgrass problems in the two stubble-mulch fallow treatments. The disk and sweep treatments contained significant densities of cheatgrass and that weed was considered uncontrollable in those treatments. Measurements of water and soil runoff from these tillage comparisons showed that water runoff during certain years was as high as 1.7, 1.7 and 0.7 acre-inches of water in the plow, disk and sweep treatments, respectively. Likewise, the amount of soil eroded from those treatments was as high as 19.7, 19.2, and 0.3 tons per acre, respectively.

The experiment at Pendleton continues to be maintained and evaluated nearly eighty after it was established. Some changes were made during 1947. During the first seven years the moldboard plow had provided the highest yields of winter wheat, without any effect of depth of tillage. The depth treatment was discontinued so that plowing of all plots was at a single depth (8-inches). Also, one phase of the experiment was terminated, meaning that yields from thereon were collected only during alternate years. Annual weeds and cheat grass had been problematic in the sweep treatment. The introduction and use of 2,4-D had reduced the influence of annual weeds but the cheat grass problem kept getting worse. Camara et al. (2003) evaluated effects of these tillage and nitrogen treatments on yields of winter wheat over a 53-year period at Pendleton, from 1944 to 1997. Separate evaluations were made for four groups of years ranging from periods of 10 to 25 years. They confirmed earlier conclusions that the moldboard plow system produced greater wheat yields than the two conservation tillage systems. The optimum amount of nitrogen for producing maximum yields at Pendleton varied among the four time periods they evaluated, roughly in proportion to the amount of rainfall that occurred during the years of those same time periods. During one period the optimum yield was achieved with additions of 40 pound of N/acre, and in another period in which most years had above-average rainfall the optimum occurred at 80 pound of N/acre.

Machado (2011) re-evaluated results of the tillage-fertility experiment over a 14-year period from 1984 to 2003. He also found that the moldboard plow system produced greater wheat yield (52.4 bushels/acre) than the two conservation tillage systems, for which the 14-year mean yield was 48.6 and 46.8 bushels/acre for the disk and sweep systems, respectively. The best average yield over that time interval was achieved by adding at least 80 pound N/acre (52.4 bushels/acre). Yields were lower when 40 pound N/acre or no nitrogen was added; 48.6 and 35.5 bushels/acre, respectively.

A different but similar experiment with tillage and nitrogen rate variables was conducted at Pendleton over a short period from 1962 until 1965. Three tillages (moldboard plow, one-way disk, 16-inch sweeps) and four nitrogen rates with or without sulfur (40 – 160 pound N/acre) were studied. At all nitrogen rates up to 80 pound/acre, the highest yields were with the plow, the lowest yields were with the sweep, and the disk produced intermediate yields. At 120 and 160 pound N/acre, yields in the plow and disk treatments were nearly equal and were about 10 bushels/acre higher than the sweep treatment.

These results repeatedly confirmed that conservation tillage systems tended to be less productive than clean tillage systems, which during the earliest years was attributed to poorer control of downy brome, among other factors. The advent of new herbicide technologies, discussed in Chapter 21, has provided opportunities to overcome some of the limitations experienced with conservation tillage systems.

Methods for Establishing and Maintaining Fallow

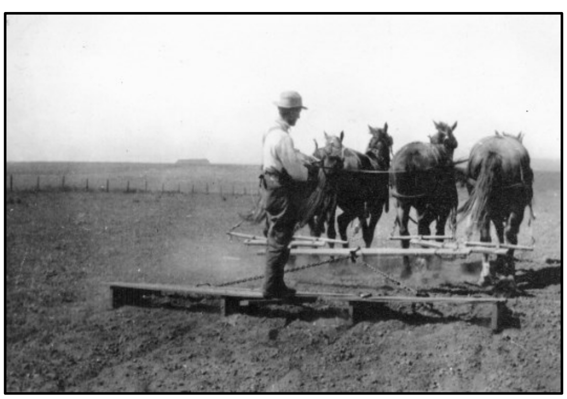
Establishing fallow

A 27-year experiment at Moro, from 1927 until 1954, evaluated 10 different methods to prepare and maintain summer fallow. The variables included three spring plowing dates, two depths of plowing, and different surface finishing treatments, including stubble-mulch versus black fallow, packing versus harrowing the soil immediately after plowing, delaying harrowing for three weeks after plowing, not harrowing at all, burning the straw before plowing, and maintaining soil quality by using wheat straw versus pea straw. Fourteen additional treatments were ultimately added to that experiment during its first decade. All treatments were evaluated by determining net profitability.

It was again determined that plowing during early spring produced the highest wheat yield, that the depth of plowing had little difference on wheat yield, and that shallow plowing provided greater profitability. Land plowed during April or early May and then harrowed only once following plowing lost considerably more moisture during the following months compared to land harrowed frequently to maintain a good soil mulch and to destroy weeds. But the soil harrowed only once allowed much better infiltration of the rains during September. Overall, harrowing did not improve wheat productivity or profitability over land that was not harrowed. Packing the soil immediately after plowing with a Campbell subsurface packer did not help to conserve moisture or improve wheat yield. The greater water requirement of winter wheat grown on June-plowed ground compared to plowing in April or early May was interpreted as a deficiency of plant nutrients in fields plowed during June. Immediate rod weeding produced the highest 18-year average yield of winter wheat (by 0.5 bushels/acre) but also had the disadvantage of opening the soil to greater erosion, and placing a greater amount of stress on the farmer. Delayed rod weeding spread the workload on the farmer and also let the clods harden so they didn't pulverize, leaving a cloddy surface that resisted wind and water erosion. All of this came at the expense of some wheat yield. Results of that work in this and other experiments allowed the scientists to identify the water requirements of winter wheat, spring wheat, and field peas.

Maintaining fallow

One of the pioneering contributions of tillage experiments at the Sherman Station was the introduction of an implement we now call a rod weeder. The Annual Report for 1913 included the following observations. "*In 1913 an implement called a 'bar weeder' was used for cultivating summer fallow, which was found to be much more effective than the spike-tooth harrow*." The new implement was then described. "*The bar weeder is superior to either the disk or spike-tooth harrow because it will do the weeding more effectively and yet not finely pulverize the surface soil*." The wheat industry in the region quickly adapted the newly-introduced bar weeder. That implement was then quickly surpassed by another innovation; a modification that replaced the stationary bar with a rotating square rod. The rotating rod reduced the amount of 'plugging' caused when long wheat straws became hung up on the stationary bar. The early introduction of the rod weeder at the Sherman Station continues to be an important part of nearly all cultivated wheat-fallow rotations at the present time.



A bar weeder being used to remove weeds from summer fallow at the Sherman Station; August 1913

Chemical fallow

An early experiment at Moro showed that winter wheat on land that was maintained as a conventionally rod-weeded stubble mulch tillage between the time of plowing during the spring and planting during the fall yielded 37 percent more grain than land that was not tilled during that interval; average yields were 34.9 and 21.9 bushels/acre, respectively. Those results represented agriculture at a time when there were no practical weed control options other than mechanical tillage or grazing.

During the 1940s and 1950s there were great advances in the introduction of more and better herbicides to control weeds. This introduced a new opportunity to examine winter wheat-fallow systems for which the fallow was not tilled.

In 1959, Dean Swan established and experiment at Pendleton to compare mechanical fallow, chemical fallow, and a combination of chemical and mechanical fallow. During the first three years, the chemical fallow produced yields that were 6 to 7 bushels/acre lower than the other two treatments, and that occurred at all three rates of nitrogen application being tested in that experiment. The results were consistent until the experiment was terminated in 1966.

Growth of Russian thistle in fallow after spring wheat (left) but not in fallow of winter wheat (right), in 1920

In 1960, Swan also established an experiment to examine the potential of using chemicals to maintain weed-free summer fallow at Moro. He compared chemical fallow, mechanical fallow prepared with a sweep, and a mixture of those practices. After 10 years, the final 5-year average yields were highest for the combined practice (24.2 bushels/acre), lowest for strict chemical fallow (16.2 bushels/acre), and intermediate for the sweep plow treatment (22.2 bushels/acre). At that time, Dr. Don Rydrych, who succeeded Swan, also reported 5-year averages from another experiment that evaluated the combinations of fallow type and timing. Averages were as follows for the treatments of early plowed-normal tillage (17.1 bushels/acre), early disk-late plow-normal tillage (18.4 bushels/acre), chemical fallow-late plow-minimum tillage (10.2 bushels/acre), chemical fallow-early plow-minimum tillage (14.6 bushels/acre), and chemical fallow-late plow-normal tillage (14.9 bushels/acre)

In another of Rydrych's weed control investigations, the downy brome problem was always least important in the moldboard plow system and of great importance in the stubble-mulch and no-till systems. Even when the downy brome was controlled with an herbicide application, the yield of winter wheat in Rydrych's trials was always greatest in the moldboard system than the two conservation tillage systems.

Attempts to eliminate fallow

When the Sherman Station was established, it was already known that the presence of a fallow phase in the cropping system was depleting the amount of soil organic matter in the upper foot of the soil profile. One of the earliest studies was an attempt to eliminate or to at least reduce the frequency of fallow. The first of those experiments was designed to identify the best method for establishing a stand of spring wheat on land cropped to winter wheat or spring wheat the previous year. The study showed that wheat productivity was highest when plowing was done as early as possible during the spring. The early spring plowing dates produced more spring wheat than moldboard plowing or disking during early or late fall. However, most of the early studies focused on winter wheat because farmers had already determined that winter wheat was more productive than spring wheat, if the winter wheat was rotated with fallow.

The earliest attempts to eliminate fallow failed because it was found that the original function of fallow had been "*to accumulate moisture and nitrates*." But many areas in the region have shallow soil which receive enough moisture in one winter to fill the profile. Fertilizer applications had become common by the 1950s and this practice eliminated the need to accumulate nitrate during the fallow period. Likewise, erosion had been reduced by leaving standing stubble on the land during the winter, and stubble-mulch fallow reduced soil erosion during the rest of the year.

These advances led to a renewed interest in growing wheat annually to eliminate the fallow phase. However, if farmers desired to grow wheat annually, they needed to know what amount of soil water was required in the spring to afford an opportunity to produce a crop on re-cropped land. They also needed to know how much nitrogen could be applied economically, and whether they could produce yields each year that were equal to at least half the yield of winter wheat rotated with summer fallow. Annual wheat experiments were therefore established at Moro during 1952. The annual cropping trials included spring wheat and winter wheat, each of which was compared with a winter wheat-fallow rotation within the same experiment. Ten years later, in 1962, the annual spring wheat and annual winter wheat had each produced more wheat than wheat after summer fallow in each of the 2-year periods for which data was collected. However, the yields of annual winter wheat were highly variable from year to year, with two total crop failures included in those averages.

Maintenance of soil organic matter in wheat-fallow

Moro

In order to determine if the rate of depletion of soil organic matter could be reduced or even reversed, a crop residue experiment was conducted at Moro from 1923 until 1954. Measurements of soil water and nitrogen were made each year at 1-foot increments to a depth of six feet. Treatments included:

1) adding 10 tons of strawy manure to standing stubble in the spring, and then chopping stubble with a disk before turning it under with a moldboard plow,
2) disking stubble in the fall before plowing in the spring,
3) disking in the spring before straw was turned under by plowing, and
4) burning stubble during the spring before plowing.

In 1932, after 10 years, the plots that received strawy manure before each of the five crops of winter wheat, and plots with all straw returned and turned under, had the highest soil nitrogen and soil organic matter in the first foot of soil. The burned plot had less of these constituents, and the least amounts were found in the disked binder stubble plots. There were no differences in nitrogen or organic matter below the first foot of soil. In 1951, after 28 years and 14 winter wheat crops, the mean wheat yields in each treatment were essentially the same; 27.6, 26.9, 28.2 and 27.2 bushels/acre.

Pendleton

An experiment similar to that at Moro was established at Pendleton during 1930. The 1956 Annual Report stated reasons that the crop residue experiment was established: "*At the time the Pendleton Branch Experiment Station was established it was a common practice throughout the wheat growing area of the Columbia Basin to burn the wheat straw before plowing. This, in many instances, was almost a must since farm equipment such as plows and disks were not designed to handle the heavy wheat stubble which was being produced. Wheat yields were also markedly reduced when this heavy stubble was plowed back into the land. It was realized that the continuous burning of all of the crop residue that was produced would eventually result in decreased fertility as measured by organic matter and a breakdown of the soil structure. The experiment was designed to show the effect that burning the straw year after year would have on the fertility of the soil as measured by wheat yields. It was also felt desirable to try and determine the amount of nitrogen that would be necessary to add with the straw in order to bring production on a level or surpass that obtained when the stubble was burned. It was also felt desirable to add organic nitrogenous materials such as pea vines and strawy manure to the soil to determine what effect these materials would have on the physical condition of the soil over the years as well as their influence on the productive power of the soil*."

The following nine pre-treatments were followed by inversion tillage with the moldboard plow during the spring to establish a fallow phase before planting winter wheat. The treatments included

1) returning all combine harvester stubble by disking during fall,
2) returning all combine harvester stubble by disking during spring,
3) addition of 30 pound of N/acre to wheat stubble and disking during fall,
4) addition of 30 pound of N/acre to wheat stubble and disking during spring,
5) burning the wheat stubble during fall,
6) burning the wheat stubble during spring,
7) adding 1 ton of pea straw to wheat stubble in the spring,

8) adding 10 tons of strawy manure to wheat stubble in the spring, or
9) plowing all wheat stubble without disking.

During the first decade the wheat yields were consistently about 2 bushels/acre higher on plots where the straw was burned as compared with being turned into the soil. In 1953, the 23-year average winter wheat yield was about 2 bushels/acre higher if the stubble was burned during the spring than during the fall. But at the same time, the initial differential in yields for the straw-burned and the straw-retained plots had been diminishing. During the second decade of the experiment the average yield was slightly higher where the straw was incorporated rather than burned. Yields in all treatments generally increased over time but it was also documented that the moving average for precipitation also steadily increased; 14.2 inches from 1931 to 1940, 17.5 inches from 1939 to 1948, and 17.5 inches from 1942 to 1951. Highest average yields in 1953 were from treatments with manure (51 bushels/acre), pea straw (47 bushels/acre), or plowing without disking or disked in fall or spring and fertilized (30 pound N/acre) before plowing (44-45 bushels/acre). The three lower-yielding treatments (#1, 2 and 9) were discontinued.

Summaries during 1955 and 1960, after the 25th and 30th crops of winter wheat, indicated that decomposition of straw had been greater and yields were increased where 30 pounds of N had been added to the stubble. The fertilized plot yielded an average of 4.7 bushels/acre more than where the stubble was burned. The addition of pea straw and manure resulted in the highest yields, and they were higher than in plots fertilized with equivalent amounts of commercial nitrogen. Intensive samplings of the trial at five 1-foot depth intervals indicated that soil moisture storage efficiency was greater in fallow of the manure and pea vine treatments than the equivalent commercial fertilizer treatment, and the non-fertilized and burned-stubble treatments had the poorest water storage efficiency.

In 1966, Merrill Oveson published a 36-year summary (Oveson, 1966) of the trial. The 35-crop average yields were as follows: addition of strawy manure (50 bushels/acre), addition of pea straw (45 bushels/acre), and addition of 30 pound N and disking during the fall (44 bushels/acre) or spring (43 bushels/acre) before the plots were plowed. All non-fertilized treatments, with or without burning the stubble, had average yields between 35 and 39 bushels/acre. After consultation with other scientists at Corvallis and Pendleton, the experiment was modified. Treatments that continued included burning stubble during the fall or spring, applying strawy manure or pea vines, and the non-fertilized checks. New nitrogen application rate treatments were initiated and the variety planted was changed from standard-height varieties to Nugaines, a soon-to-be released semi-dwarf variety. Another revision was made in 1978, in which two previously non-burned fertilized treatments began to be burned during the spring. All treatments continued to be moldboard plowed during the spring after pre-treatments had been applied. In treatments receiving commercial fertilizer, applications are made immediately before planting the winter wheat. Crops produced during 1979 and thereafter have had the following treatments:

1) addition of 40 pound N/acre and stubble burned during the spring
2) addition of 80 pound N/acre and stubble burned during the spring
3) addition of 40 pound N/acre and stubble is incorporated
4) addition of 80 pound N/acre and stubble is incorporated
5) non-fertilized since 1931 and stubble burned during the fall
6) non-fertilized since 1931 and stubble burned during the spring
7) adding 10 tons of strawy manure to wheat stubble in the spring,
8) adding 1 ton of pea straw to wheat stubble in the spring, or
9) non-fertilized and not burned since 1931

Many publications have been produced to report results of research conducted on this experiment. The most recent publications were by Machado (2011), Ghimire et al. (2015), Smiley et al. (2016), and Ghimire et al. (2018). Findings regarding carbon, nitrogen, water-use efficiency, soil pH, plant diseases are discussed in chapters pertaining to those subjects. Grain yield data for all nine treatments have not been published recently. Machado (2011) published yields for six treatments (#3, 4, 5, 7, 8 and 9) during a 22-year interval (1982 to 2004). The highest average yield was in the manured treatment #7 (52.4 bushels/acre). Intermediate yields were in the 80 pound N/acre treatment #4 (44.9 bushels/acre), and in the 40 pound N/acre (#3) and the pea straw (#8) treatments (39.3 bushels/acre). Lowest yields were from the non-fertilized non-burned treatment #9 (26.2 bushels/acre) and the non-fertilized fall-burned treatment #5 (24.3 bushels/acre). Ghimire et al. (2018) published wheat yields for four non-fertilized treatments during a 15-year interval (1996 to 2010). The highest yield was in the manured treatment (89.0 bushels/acre). The pea straw treatment produced an intermediate yield (67.9 bushels/acre) and the lowest yields were in the non-fertilized non-burned treatment (46.9 bushels/acre) and the non-fertilized fall-burned treatment (43.2 bushels/acre). While the rankings of these yields are presumed to be relative within individual publications, it also appears that the magnitude of reported yields differs by a factor of two from one paper to another, suggesting that there may have been a calculation error in one or more papers.

In-Crop Tillage

Harrowing the growing winter wheat crop in the early spring was a long-standing practice when the Sherman Station was established. The farmers believed that it served three functions: it killed weeds, it created a mulch, and it reduced moisture loss from evaporation. Some farmers believed the harrow treatment stimulated additional tillering, while others believed it thinned the stand of wheat plants. Later, some farmers harrowed during the spring to partially fill the deep furrows created by deep-furrow drills, to make the land easier to harvest.

A 41-year experiment at Moro, from 1914 to 1954, concluded that average yields were essentially the same for winter wheat that was harrowed or not harrowed during the spring; 23.7 vs 23.4 bushels/acre, respectively. However, there was a trend for harrowing to impart its greatest advantage during the wettest, highest-yielding crop years. Nevertheless, well-established weeds weren't always killed. The practice was ultimately determined to be non-economical. It was mostly abandoned from the 1950s until the 1990s, when additional studies of in-crop tillage combined with a low-dose application of herbicide was studied as a low-cost option for controlling downy brome. A combination of applying herbicide and then skew-treading on dry soil during early spring successfully reduced the downy brome density without harming the wheat stand. More detail is provided in Chapter 21.

Strip-Tillage System

As stated earlier, production of winter wheat without tillage became more successful in the 1960s when improved herbicides became available for maintaining a weed-free chemical fallow. In 1978, Dr. Floyd Bolton began to study a planting system that could potentially improve wheat productivity in no-till cropping systems. The existing no-till drills used heavy coulters or chisel points to open a slot into which the seed could be buried into the previously undisturbed fallow. That approach sometimes was impeded by some soils that had a very hard and dry surface at the time of planting, which resulted in poor contact of the seed with soil that had sufficient moisture to provide prompt seed germination and seedling emergence. If the planting was made to reach a depth with sufficient moisture, the seed was often planted too deep for adequate seedling emergence. Also, where heavy residue had remained on the soil surface, the no-till drills sometimes plugged and the seedlings were weakened by either toxic substances or plant pathogenic fungi that emanated from that old residue.

Bolton's approach was to design a rotary strip-tillage system that prepared narrow tilled strips four inches wide that were spaced 18 inches apart (Bolton and Booster, 1981). Tillage in the strips could be accomplished to a depth of up to seven inches. The intent was to till to the depth where seed zone moisture was sufficient to germinate seed, and using wide shovels to push most of the over-riding soil out of the tilled strip to prevent seeds from being covered too deeply. The seed was dropped through double-disk openers and the covered seed was packed with a packer wheel. The strip-till system enabled the seed drill to move through heavy residues without plugging and it also produced excellent seed-to-soil contact. Tillage within the row eliminated previous problems encountered with toxins or pathogens from the residue. Importantly, yields for the strip-till system were nearly comparable with yields in the stubble-mulch tillage system but required four times fewer field operations over a 2-year cropping cycle. Bolton also evaluated the feasibility of injecting water into the seed zone at the time of planting with the strip-till drill. He found that dripping any amount of water (from 45 to 135 gallons per acre (0.2 to 0.6 ounces per foot of row) into the seed zone generally increased the speed of seed germination, the density of seedling stands, and grain yield. This was accomplished in soils that had seed-zone moisture contents of 7.5 to 8.5 percent at the time of planting. The system was particularly successful during a year in which there was greater-than-usual precipitation, resulting in an increase of yields by 21 to 29 percent where any amount of water was injected. Bolton continued to develop the system by examining weed control practices, seeding rates, and fertilizer rates. A company in Yakima, WA modified and commercialized the strip-till drill as new findings emerged from Bolton's research.

Tillage Systems for a Wheat-Pea Rotation

A wheat/pea rotation experiment with tillage variables was established at the Pendleton Station in 1963, by Dr. Robert Ramig and Merrill Oveson. The experiment was initially known as "the cloddy seedbed experiment." Its objective was to determine the effects of four tillage regimes on soil properties and productivity in a winter wheat-spring legume annual crop rotation. The experiment focused on spring-planted canning pea for several decades and was converted to a dry seed pea during the most recent three decades. Each replication contained eight plots; four treatments duplicated within each crop species. Duplicate treatments, offset by one year, permitted collection of wheat and pea data each year. The basic treatments are shown in the table.

In all treatments, herbicides were used to control weeds before planting wheat or peas. The maximum tillage treatment was considered to be the farmer's normal practice in 1963. The stubble was disked twice after the wheat harvest and were cultivated by sweep tillage followed by several passes of the rod weeder and a roller-packing operation before peas were planted in the spring. The soil was chisel plowed after pea harvest and then rod weeded several times during the fall, before planting wheat. This procedure created a rough soil surface to resist erosion during the seedling growth period of the winter wheat.

For the fall plow treatment, wheat stubble was moldboard plowed during the fall and cultivated several times with a field cultivator before peas were planted and then roller-packing the newly-planted soil. After pea harvest, the soil was moldboard plowed, cultivated several times, and planted to winter wheat during the fall. This dry-tillage treatment left a cloddy soil surface that resisted erosion.

The spring plow treatment had standing wheat stubble until spring, which was inverted by moldboard plow and cultivated several times before the peas were planted and the soil roller packed. After pea harvest the soil was treated the same as in the fall plow treatment.

Tillage treatments in the wheat-pea rotation experiment at Pendleton

Treatment		*Primary tillage*	
No.	Name	Wheat stubble	Pea vines
1	Maximum tillage	Disk (fall)	Chisel (fall)
2	Fall plow	Plow (fall)	Plow (fall)
3	Spring plow	Plow (spring)	Plow (fall)
4	No-till	No-till	No-till

From 1963 until 1996 the no-till treatment was cultivated with a shallow sweep (at 2-inch depth) after harvesting each crop. Thereafter, the wheat stubble has been chopped with a rotary mower and skew treaded during the fall. Peas were planted without further tillage during the spring. After pea harvest, the pea vines were chopped and stirred into soil to 1-inch depth by using a sked treader. The wheat was then planted without further tillage.

Early results showed that reduced tillage led to a reduction of tenderometer readings for peas and a higher test weight for wheat. In 1968, it was shown that when wheat stubble was left standing during the winter the soil to 8-foot depth stored 7.3 inches (90 percent) of the total 8.1 inches of precipitation between August 1 and April 9. In contrast, where wheat stubble was plowed under during the fall, the soil to 8-foot depth stored only 2.7 inches (34 percent) of the total 8.1 inches of precipitation. The pea crops from these respective treatments used 5.1 or 1.9 inches of the stored 7.3 or 2.7 inches. The difference of water extraction by peas (3.2 inches) resulted in an additional 1300 pounds of peas per acre, or 400 pounds per inch of additionally stored water. None of the 2.5 inches of rain that fell between pea harvest and wheat planting was stored; in fact an additional 0.25 inch of water was lost from the profile during that interval. The wheat that followed peas also benefited from the extra water retained by the previous standing stubble treatment. The difference of residual water was 0.8 inch and it produced an additional four bushels of wheat, or about 5 bushels of wheat per inch of water.

This cloddy seedbed experiment was intended to be terminated in 1969, after four crops of wheat and four of peas. However, poor control over volunteer wheat and cheatgrass during 1966 and 1967 led to invalid results those years. The termination date was therefore extended until 1971. However, in response to a request by green pea producers, the experiment was in actually expanded by placing experiments with four, five or six tillage treatments at six off-station sites. The goal was to make these comparisons of treatments on two other soil series (Palouse and Athena silt loams) in Umatilla County, to complement the results already achieved on the Walla Walla silt loam at the Pendleton Station. Those experiments were established at the Rea, Howard, Johnson, Lieuallen, Barnett and Adams farms. Water-use efficiency and crop yield data were collected at all sites. Overall, green canning peas produced 308 pounds for each inch of water extracted and NuGaines winter wheat produced 3.38 bushels for each inch of water. The off-station sites were terminated after two or three years but the study at the Pendleton Station is still being maintained in 2018.

Recently, all tilled plots are planted using a John Deere 8300 double-disk drill with 6.8-inch spacing, and all no-till plots are planted using a John Deere 1560 drill with 7.5-inch spacing. All fertilizer is applied as preplant shank-applied liquid fertilizer. Tilled winter wheat plots receive 80 pound N/acre while no-till winter wheat plots receive 90 pound N/acre. All pea plots receive 16 pound N/acre. Both peas and wheat receive phosphorus (P) and sulfur (S) along with the N application. Pesticides are applied to control weeds, insects and diseases. Yields in these experiments are measured by collecting bundle samples as well as harvesting the treatments with a combine.

A summary of results from this experiment was recently published by Awale et al. (2018). Throughout this experiment, wheat yields have usually been higher when soil was moldboard or chisel plowed as compared to the no-till treatment. Awale et al. (2018) reported that wheat yields averaged over six years (2005-2010) were 81.3 and 80.0 bushels/acre for the fall plow and spring plow treatments, respectively. The average yield in the maximum tillage and no-till treatments were 75.7 and 70.1 bushels/acre, respectively. It was shown earlier in the experiment that the fall plow treatment resulted in a higher number of plants per square foot than the no-till treatment, and that plant stands did not differ between chisel after peas and spring plow treatments. The lower grain yield in the no-till treatment than in all other treatments has consistently been associated with observations that the no-till treatment tended to have a higher infestation of downy brome. Grain protein content has also been higher in the no-till treatment than in the other treatments.

Pea yields have always been significantly lower in the fall plow treatment compared to the other three tillage treatments. Awale et al. (2018) reported recent data showing that pea yields in the fall plow treatment averaged 2,076 pound/acre over a six-year period (2005-2010), compared to yields of 2,412, 2,480 and 2502 pound/acre for the maximum tillage, spring plow, and no-till treatments, respectively. Yields in all treatments were strongly responsive to winter precipitation and growing season precipitation and temperature. No-till plots had lower plant populations but compensated by producing more pods per plant. Treatments did not have an effect on kernel weight and pods/ft^2.

Off-Station Tillage Experiments in Umatilla County

The Pendleton Station scientists leased land at four off-station sites to conduct long-term tillage and residue management trials in Umatilla County. Sites selected during the 1950s were called 'pilot farms' indicating that they were intended to serve as demonstrations of the best possible farming practices in each region. These research sites were introduced in Chapter 5. They included the

1. *King Pilot Farm*: west of Helix; 12.5-inch precipitation; 1949-1962,
2. *Hill Pilot Farm*: west of Helix; 11.7-inch precipitation; 1950-1959,
3. *Crow Pilot Farm*: south of Weston; 16.4-inch precipitation; 1950-1964, and
4. *Reese Farm*: between Echo and Pendleton; 11.4-inch precipitation; 1974-2018.

King and Hill Pilot Farms

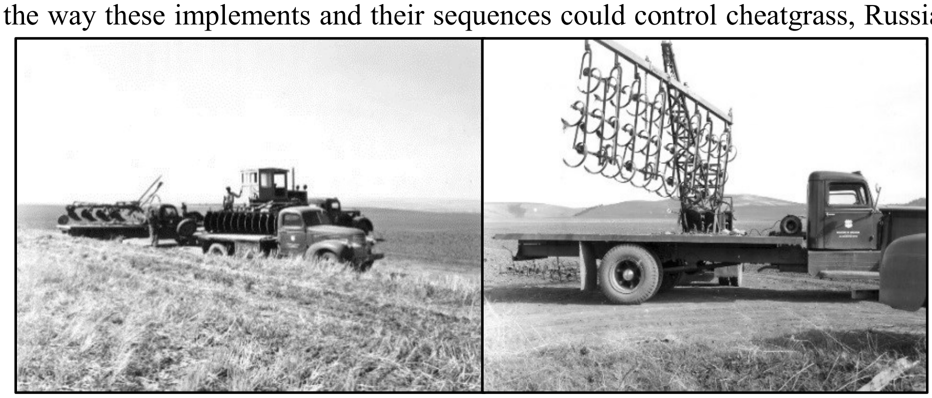
This pair of sites was selected to test a wide variety of fallow tillage practices under low-rainfall conditions. The sites were near one another and had offset phases of a winter wheat-fallow rotation to allow data to be collected from each experimental phase each year. Merrill Oveson and Ted Horning compared the uses of stubble busting equipment, skew treaders, spring tooths, sweeps, mulching equipment, and grain drills. At one point, Horning examined the efficiencies of five different types or configurations of seed drills to compare deep-furrow, semi-deep furrow, double disk, and shoe openers. Sources and rates of nitrogen fertilizer (anhydrous ammonia vs. 16-20-0, from 0 to 40 pound N/acre) were also compared in different residue-retention systems, including plowing, disking or sweeping. Nitrate and moisture contents at 1-foot depth intervals to six feet depth were examined for most of the tillage and fertility variables. Detailed data for each year were published in the Annual Reports from the Pendleton Station. Some reports included large numbers of photographs of equipment and soil surfaces, and a summary of results. From 1950 to 1955 the experimental results had been the same or very similar at these sites. The fallow tillage study was therefore terminated at the Hill Farm in 1955 and other experiments and the lease were terminated in 1959. The fallow tillage study was continued at the King Farm until after the harvest of 1959, and the lease was terminated after the harvest in 1962. During 1957, some erosion occurred on steeper slopes where wheat had been planted into moldboard plowed soil, but the soil-conserving stubble mulch tillage completely eliminated soil erosion.

One of the studies at these farms and at the Pendleton Station involved loading the soil with extra straw to simulate conditions in higher rainfall areas. During 1957, the scientists were amazingly able to prepare a successful fallow with an overburden of 12,000 pound of stubble per acre at the King Farm. They broke the straw with a stubble buster the day before the first rod weeding. They used an end-drive rod weeder two times during the summer and once just prior to planting, all of which occurred without plugging or bridging the equipment. Winter wheat was planted without plugging the John Deere HZ-prototype deep-furrow drill equipped with 6-inch wide shovels on two staggered toolbars to achieve a 14-inch row spacing without the use of straw walkers on a single line of split-packer wheels. The stubble busting, rod weeding and planting operations were illustrated by amazing photographs on pages 104-108 of the 1957 Annual Report. The good wheat stands in furrows had solid layers of straw remaining between wheat rows. The scientists concluded that equipment was now available to effectively prepare fallow and to plant into soil with a heavy overburden of straw on or near the soil surface. They also reported that their work activities on extra ‘practice’ plots for each treatment, which were adjacent to the actual experiment, were indispensable for trying out and adjusting the equipment before they moved the equipment into the actual experimental plots.

Successfully rod weeding and planting deeply into heavy reside using a John Deere HZ deep-furrow drill at the King Pilot Farm

In 1957, the station scientists also established a new experiment at the Hill Farm, where cheatgrass had been a continuing problem for growers and was considered severe in about one out of every four years. At that time, cheatgrass problems sometimes governed whether a farmer continued the stubble mulch tillage practice or reverted to clean tillage. The new study was established to determine what implements could control cheatgrass most effectively, how many tillage operations were necessary, and what sequences and timings were most effective for the various implements. The study was prepared by using a ‘once over tillage’ during the spring of 1956, which resulted in a stand of cheatgrass three times denser than would be considered normal. These tests included the use of a Noble 2-shank sweep, two types of spring-tooth cultivator, center-drive rod weeder, and skew treaders with or without spirals. Eight different sequences of these implements were tested in 20 × 150 foot plots replicated four times. The scientists found very important differences in the way these implements and their sequences could control cheatgrass, Russian thistle, and broadleaved weeds.

The 1955, 1957 and 1958 annual reports contained detailed summaries of results achieved in the fallow tillage studies at the Pendleton Station and at the King and Hill farms. Among the most important findings were the following.



Loading station equipment after applying tillage treatments at the Hill Pilot Farm

Wheat yield and soil fertility:

1. Wheat yields were higher after moldboard plowing than after the sweep, double disk or one-way disk plow.
2. Wheat yields were equal on rough (cloddy) and 'worked' seedbeds.
3. Plowing during the fall showed no advantage or disadvantage to early spring plowing for fallow, as measured by wheat yield.
4. Rotary subsoiling or disking stubble in the fall showed no advantage (wheat yield) compared to land where stubble was left standing over the winter, even during the 20 percent of years (1 out of every 5 years) where more soil moisture was stored following the rotary subsoiling.
5. Moldboard plowing to 8-inch depth yielded more than plowing to 5-inch depth.
6. Addition of phosphorus and sulfur with the nitrogen did not increase wheat yield, over nitrogen applied alone.
7. An additional 20 pounds of nitrogen were needed to maintain wheat yields in stubble mulch fallow, as compared to clean moldboard plowed fallow.
8. Nitrate accumulation under various tillage and rotation treatments was extremely variable, which made the data difficult to interpret.
9. Plots receiving the highest nitrogen rates depleted the available moisture supply faster than did wheat receiving lower rates of nitrogen.
10. Nitrogen supplied as organic material with a narrower C:N ratio than is present in wheat straw, such as pea vines, resulted in higher yields than could be obtained with the same application rate of commercial nitrogen.
11. Width of row spacings on four types of seed drills had no effect on wheat yield.
12. Types of furrow openers did not influence wheat yields at the Pendleton Station, but the deep-furrow drill had higher yields at the King Pilot Farm, where rainfall is less.

Erosion:

13. To reduce erosion and protect the seeded crop, it was necessary to preserve all stubble possible if there was under 3,000 pounds of straw produced per acre.
14. Erosion was acceptably controlled if stubble over 3,000 pounds per acre was mulched to prevent plugging of tillage and seeding equipment.
15. Standing stubble during the winter held more snow and reduced evaporation and erosion.
16. Eroded soil and water moving from worked strips was halted by rough strips placed across the slope.
17. When the soil surface ran together and sealed over, erosion was negligible on rough seeded land but occurred on worked land even on gentle slopes.
18. Soil losses by erosion were greater on moldboard plowed than on sweep treatments.

Residue management:

19. Sweep blades of 30-inches wide or less caused ridging on steep hillsides and mixed more mulch with soil than wider sweep blades.
20. Stubble that was covered in early spring operations caused plugging of follow-up tillage implements.
21. Weather conditions during the spring were more important with regard to plugging of tillage implements than was the actual amount of mulch.
22. Spring weather had more influence on the ease of tillage than the amount of stubble present.
23. Efficient handling of mulch and weed control could only be achieved by waiting until the weather was warm, humidity was low, and soil and mulch were dry.
24. Rod weeder operation was affected by presence, direction and moisture content of buried mulch.
25. Duck foot shovels placed ahead of the weeder rod gave a more uniform penetration of the rod.
26. Center-drive rod weeders worked through heavier mulches without plugging, compared to end-drive rods.
27. Deep-furrow drills seeded through the heaviest mulches without plugging.
28. Leaving seedbeds cloddy reduced the workload for seedbed maintenance by two to three tillage operations, making it less expensive.
29. Cloddy seedbeds were harder on the drills; large clods crushed some of the tubes on the seed drill.
30. Cloddy seedbeds had fewer wheat plants but more stooling (tillers) than worked strips.
31. For conservation of moisture and weed control, it was essential to skew tread, rod weed, or cultivate with a spring-tooth harrow immediately after the spring tillage.
32. In years of light wheat stands and light cheatgrass infestation, the skew treader could achieve effective control of cheatgrass when the skew treader was attached behind the rod weeder. In years of heavy cheatgrass infestation and dense wheat stands, it was necessary to skew tread after rod weeding, using a high speed (>5 MPH) in order to shake the moist soil off the matted roots to insure drying and killing.
33. Over the long term, burning of stubble reduced the wheat yield, compared to incorporating the straw into the soil.
34. Plots receiving animal or plant residues had a tendency to enhance evaporation during the summer months, compared to evaporation from stubble-burned plots.

35. During the summer months, the third and fourth foot depths gained moisture at the expense of moisture that had been in the first and second foot depths at an earlier time.
36. A straw spreader on the combine simplified mulch tillage and seeding into mulches.
37. The need for fall tillage depended on the amount of stubble and the need for weed control.
38. The amount and condition of the mulch left on the surface at seeding time and the soil moisture conditions dictated the type of drill that was required to work through the mulch and secure a stand of wheat.

Crow Pilot Farm, near Weston

This experimental site two miles southwest of Weston was selected as site with higher rainfall than the Pendleton Station. The site was introduced in Chapter 5 and results of crop rotation studies were discussed in Chapter 12. A special feature of the tillage studies at this location was the cloddy seedbed research conducted by Ted Horning and Merrill Oveson. Enormous clods were prepared and maintained on the soil surface to control erosion. More such images are shown in the Pendleton Station Annual Reports for 1954 and other years.

The scientists concluded that this rigorous tillage research demonstrated that rough seeding was cheaper, stopped runoff from adjoining areas, and did not erode. Smoother seedbeds were expensive, did not stop runoff from adjoining areas, and allowed for soil erosion. Specifically, they found that:

1. Seeding into a cloddy seedbed completely eliminated soil erosion.
2. An average of 2 to 3 tillage operations were eliminated where seeding was done into a cloddy seedbed.
3. Wheat seeded into clods yielded the same or only slightly lower than where wheat was planted into conventional ‘black-fallow’ seedbeds.
4. Several farmers quickly adopted the practice of cloddy seedbeds because it eliminated soil erosion.

Another major emphasis of tillage research at the Crow Farm was related to methods to manage sweet clover green manure before planting winter wheat. Marr Waddoups and Merrill Oveson turned down the green manure at three different growth stages, when it was 12-, 24- and 36-inches high. They found that the amount of nitrogen in the clover at 36-inch height was double that for clover at 12-inch height. There was no difference in winter wheat yield for green manures turned down at different stages of clover maturity. Yields were a bit higher for green manure fallows made by moldboard plow than by fallows made with a sweep. During this work, the scientists evaluated equipment parameters such as number of shanks, width of blades, blade spacing, blade tilt, coulters, height of shank clearance, and construction of the frame, hitch, shanks and blades. They found that they could kill the clover during years with the driest springs but none of the equipment, including the moldboard plow, could kill the clover during a year with a wet spring. There was up to 50 percent survival of clover plants in some tillage treatments during wetter years. Some survival occurred regardless of how the clover was incorporated into soil. In all cases, up to three additional trips across the plots were required to get a complete kill. Lots of pictures were presented in the annual reports during the late 1980s.

‘Clod farming’ to control erosion at the Crow Pilot Farm

‘Undercutting’ sweet clover with a 2-blade sweep at Crow Pilot Farm

***References*:**

Annual Reports from the Sherman and Pendleton Stations (Appendices 5 and 6)

Letters sent to or from the Station Superintendents

Awale, R., S. Machado, and K. Rhinhart. 2018. Soil carbon, nitrogen, pH, and crop yields in winter wheat-spring pea systems. Agronomy Journal 110:1523-1531.

Bolton, F. E., and D. E. Booster. 1981. Strip-till planting in dryland cereal production. Transactions of the American Society of Agricultural Engineers 24:59-62.

Camara, K. M., W. A. Payne, and P. E. Rasmussen. 2003. Long-term effects of tillage, nitrogen, and rainfall on wheat yields in the Pacific Northwest. Agronomy Journal 95:828-835.

Ghimire, R., S. Machado, and P. Bista. 2018. Decline in soil organic carbon and nitrogen limits yield in wheat-fallow systems. Plant and Soil 422:423–435.

Ghirmire, R., S. Machado, and K. Rhinhart. 2015. Long-term crop residue and nitrogen management effects on soil profile carbon and nitrogen in wheat-fallow systems. Agronomy Journal 107:2230-2240.

Horning, T. R., and M. M. Oveson, 1962a. Cloddy and conventional seedbeds for wheat production in the Northwest. Agronomy Journal 54:229-232.

Horning, T. R., and M. M. Oveson. 1962b. Stubble Mulching in the Northwest. USDA Agriculture Information Bulletin No. 253. US Government Printing Office, Washington, D.C., and Oregon Agricultural Experiment Station, Corvallis, Oregon. 28 pages.

Machado, S. 2011. Soil organic carbon dynamics in the Pendleton long-term experiments: Implications for biofuel production in Pacific Northwest. Agronomy Journal 103:253–260.

Oveson, M. M., 1966. Conservation of soil nitrogen in a wheat summer fallow farming practice. Agronomy Journal 58:444-447.

Oveson, M. M., and W. E. Hall. 1957. Longtime Tillage Experiments on Eastern Oregon Wheat Land. Agricultural Experiment Station Technical Bulletin 39, Oregon State College and U.S.D.A.-Agricultural Research Service, Corvallis. 47 pages.

Smiley, R. W., S. Machado, K. E. L. Rhinhart, C. L. Reardon, and S. B. Wuest. 2016. Rapid quantification of soilborne pathogen communities in wheat-based long-term field experiments. Plant Disease 100:1692-1708.

Stephens, D. E. 1944. Effect of tillage and cropping practices on runoff, erosion, and crop yields in the wheat growing areas of Washington, Idaho, and Oregon. Pages 1-105 in D. E. Stephens, Conservation Practices on Wheat Lands of the Pacific Northwest. U.S.D.A. Soil Conservation Service, Pacific Coast Region ·· Seven. Washington, D.C. 125 pages.

Stephens, D. E., G. A. Mitchell, M. M. Oveson, and J. Belanger. 1941. Methods of disposal of crop residues for growing wheat after fallow in eastern Oregon. A 20-page addendum in D.E. Stephens. 1944. Conservation Practices on Wheat Lands of the Pacific Northwest. U.S.D.A. Soil Conservation Service, Pacific Coast Region ·· Seven. Washington, D.C. 125 pages.

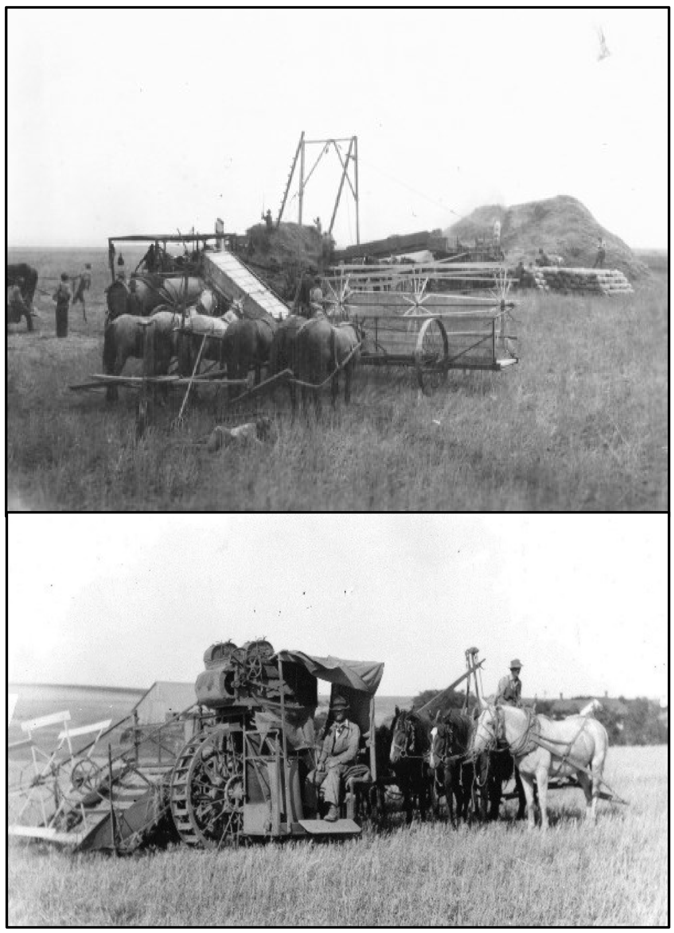
Chapter 14 - Equipment Modification, Design and Fabrication

Improvement of tillage implements and methods for managing and harvesting small plots were among the first engineering challenges faced by scientists at the dryland experiment stations. The staffs both branch stations were very clever and innovative as they modified, designed, and ordered or fabricated equipment that was often rather unconventional with respect to size, function, or practices commonly found on farms at that time.

Correspondence between the early station superintendents and equipment manufacturers vividly portrayed the role of the experiment stations in evaluating the efficiency of various types of attachments for seed drills and cultivation equipment. The Pendleton and Sherman Stations were among the first in the nation to conduct experimental tests of the deep-furrow style of seed drill.

Before the Pendleton Station was established, Dave Stephens discussed the purchase of a seed drill that would be best suited for the new experiment station. In a letter from Stephens to R. F. Whelan, Office of Dry Land Agriculture, USDA-BPI, Washington, D.C., dated October 27, 1928, Stephens wrote "*I am inclosing a voucher for $174.75 for one drill and harrow purchased from the John Deere Plow Company, Portland, Oregon. … As you probably know the title for the land for the Co-operative Field Station at Pendleton was not acquired until late in September, and it was necessary to prepare the land and seed it at the earliest possible date. … The Van Brunt drill was … better suited to our needs, as we can obtain for this drill a set of deep furrow openers to experiment with furrow seeding. … The company* [John Deere] *is loaning us a set of these attachments for use this fall, and if they prove satisfactory we shall want to purchase a set, because there is quite an interest in Umatilla County in the deep furrow seeding*."

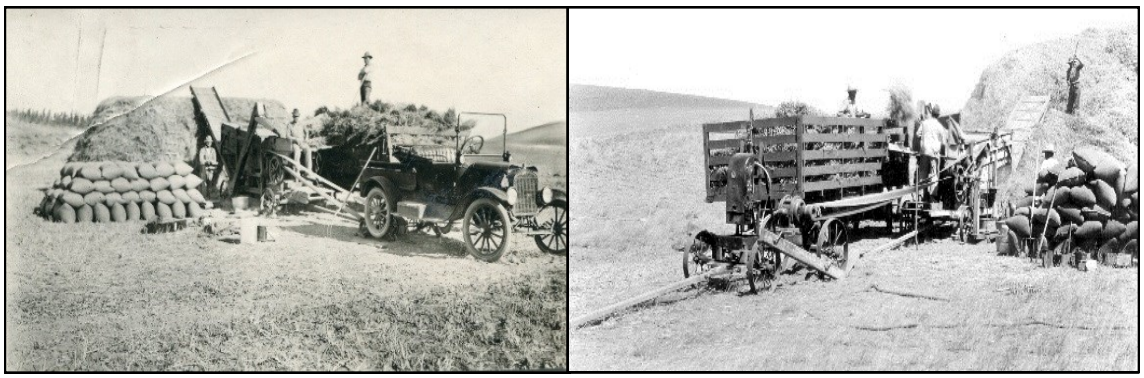
The earliest tests showed that original combinations of furrow openers, seed shoes, press wheels, and packer wheels did not perform as well as anticipated by the manufacturer. There was frequent communications between the manufacturers and Dave Stephens and George Mitchell. The John Deere company personnel also made relatively frequent field inspections to determine how to modify their equipment to increase its efficiency. The role of the stations was exemplified by a letter to George Mitchell from the John Deere Plow Co., Portland, OR, dated September 19, 1929. The letter stated, in part, "*Thanks a lot for your letter of the 18th giving us your experience with the deep furrow method of seeding as compared to the regular method of seeding. This is in line with other tests we have made, and the information is such that we do not feel we can recommend the sale of the deep furrow drills; in fact, we have constantly kept away from that until we knew more about it. We are not yet saying that the deep furrowing method is an entire failure, but we do feel, as manufacturers and distributors of farming equipment, as well as for the good of the agricultural business of the northwest, that we are not ready to recommend the sale of these machines. We will be very anxious to receive reports of your future tests …*"



Cutting wheat plants with a 6-horse push-type header at Moro (1912)

It was similarly important to develop equipment that could increase the efficiency for harvesting grain at the stations. The problem was complicated by the requirement to address at least four different types of harvest; 1) single rows of wheat (head rows), 1/20th -acre plots, 1/10th –acre plots, and larger fields planted uniformly for seed increase or other production needs. It was not possible to harvest small plots using the relatively large horse-drawn mobile combines that were being introduced onto farms at that time. At the experiment station, wheat on larger plots continued to be cut by using a header reel, pushed by a team of six horses, to cut the stems. The wheat stems and heads with grain were then transported to a stationary pile, from which the grain was separated from the stems and placed into sacks for weighing.

In 1910, Harry Umberger, the first superintendent at the Sherman Station, addressed some of the earliest needs by modifying a commercial thresher so that it could be used on the plots. Umberger explained his rationale in a four-page letter to Henry Scudder, Superintendent of OAES farms at Corvallis, dated August 17, 1910. He stated, in part, "*As per our conversation over the 'phone this morning, I have wired the Ellis Keystone Agricultural Works, at Pottstown, Pa., for a thresher. I am certain that this rig will be exactly what we want, for a number of these machines are in use on the various experiment stations, and all have given very good satisfaction. The machine I am ordering is the No. 2, which has a capacity of 250 to 300 bushels of wheat per day, and is supplied with a truck* [a 4-wheel trailer pulled by a team of horses], *a straw carrier, Tailing spout and bagger. These latter three can be removed, making it a very simple and easily cleaned little separator for plat work… The net price will be $183.60.*" They provided power by using a belt to connect the thresher to a rear tire of a Ford car. This system was used for another 15 years before the Ford became worn out and was replaced by a 10-horsepower electric motor.

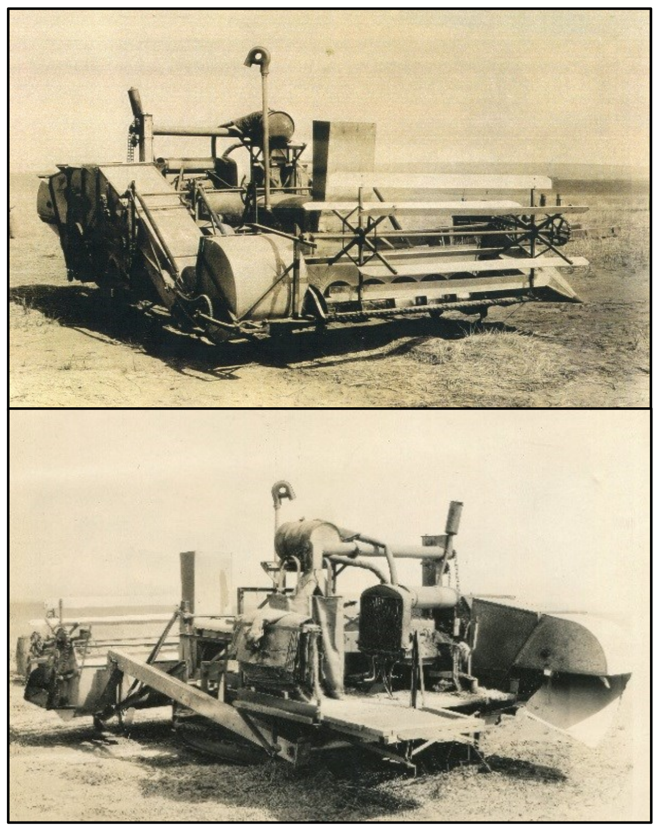


Keystone Ellis separator powered by Ford car (left) or gasoline engine (right); both in 1927

Harvest efficiency was among the important considerations when it became clear that another dryland experiment station would be established at Pendleton. In 1928, before the Pendleton Station was established, Dave Stephens was in frequent communication with L. C. Aicher, Superintendent of the Fort Hays Experiment Station at Hayes, Kansas. The primary topic of those communications was the design and efficiency of a plot threshing system that had been designed and refined at that station. In a letter to Dave Stephens, dated December 6, 1928, Aicher stated "… *After two years work with the machine here, which we rebuilt, I believe I am quite safe in saying the combine is a real success in handling experimental plats. We purchased a small Gleaner combine, which was originally built to be put on a Fordson tractor. We tore it down and rebuilt it on a small Caterpillar tractor, and mounted a new Ford motor on the combine, so that we would be able to have steady power. This scheme worked out very nicely this past year. I am inclosing you herewith some photographs of this machine in action. … The old tenth acre plats, two rods wide, work out very nicely with this small combine. It has an eight foot cut, and you will note it is a push affair. If you should buy a tractor I would urge by all means that you buy the Caterpillar.* …" Aicher had previously indicated that a

Keystone Ellis Separator and sacks of grain at the Sherman Station (1912) thresher mounted on a wheel tractor couldn't be turned tight enough in alleyways to avoid crushing or overrunning the next series of plots. Stephens then travelled to the Fort Hayes Experiment Station to see exactly what would be required to construct a similar machine at Pendleton. Stephens discussed with George Mitchell the details of the harvester he had seen in Kansas. Mitchell then made a request to purchase the necessary components. In a 2-page letter to Ellery C. Chilcott, Agriculturalist-in-Charge, Dry Land Agriculture, USDA-BPI, Washington, D.C., on April 18, 1929, Mitchell outlined the harvest requirement and the equipment that he and Stephens were requesting to address that need. He explained that the Pendleton Field Station had no equipment to harvest the experiments, and that the harvest season was quickly approaching. It stated, in part, "*The combine method of harvest is the only one used in this section, we should use a method similar to that of the farmer. … The Fordson tractor is not being manufactured at present, also it does not have sufficient power nor ability to turn short enough for experimental plat work. … The tractor we would like to use is a Caterpillar "Fifteen". It will handle a Gleaner combine very nicely*. …" Mitchell then described the many attributes of the Caterpillar, and its sales and service at the local A.E. Page Machinery Co. Mitchell requested permission to purchase without competitive bids a Gleaner-Baldwin combine ($1,020), Caterpillar Fifteen tractor ($1,580), Ford engine ($160), and expenses to cover the labor and materials during construction of the harvester by a local blacksmith (≈$200).

The custom-built thresher at Pendleton worked very well and was soon catching the attention of administrators at other experiment stations throughout the western U.S.. In particular, on February 3, 1931, Henry Wanser, Superintendent of the Adams Branch Experiment Station at Lind, WA, wrote to George Mitchell "*I am interested in learning more about how you have a Baldwin Gleaner combine attached on the caterpillar tractor. Have you a picture of it or a published report … giving a description …*" Wanser wrote again on March 13 to indicate "*Thank you for sending me the pictures of the Gleaner combine. …"* He then stated that other scientists at Pullman were also inquiring about making "*… the same kind of combination so presume that one will be purchased in the state of Washington this year. I would like to see yours work and hope to be able to visit your station this summer*." By 1933, these plot-threshing machines were being produced and used at most of the agricultural experiment stations in the western U.S.



Gleaner combine powered by a Ford Model T motor; each were mounted on a Holt Caterpillar 15 tractor (1929)

The Caterpillar tractor was quickly put to use for other practices when it wasn't being used as a platform for the harvest equipment. George Mitchell reported to his superiors in Washington, D.C. that "*… We are now doing our fall plowing with the* [Caterpillar 'Fifteen'] *tractor. …*" (in a letter to R.F. Whelan, dated September 25, 1929). At the same time, Mitchell asked the John Deere Plow Co. to "*Please send to the Pendleton Field Station a tractor hitch for a 16/6 Van Brunt drill. …*" (in a letter dated September 26, 1929). Shortly thereafter, Mitchell also informed the International Harvester Co. "*The Pendleton Field Station is in the market for a four section spring tooth harrow, with a tractor hitch. … Please send descriptive literature with quotation. I would also like literature on corn planter, mower, rake, two row corn cultivator, manure spreader, duckfoot cultivator, one way disk, and a combined grain and fertilizer drill.*" (in a letter dated February 8, 1930). The harrow with a tractor hitch was purchased almost immediately.

There was a time of transition when the drawbars of some equipment was converted from being horse-drawn to tractor-drawn, and some equipment was replaced with new equipment on which the drawbar was designed to be pulled with a tractor. This was necessary because the frames of some types of equipment that tracked properly behind horses could not be re-designed to track properly behind a tractor. Interestingly, the stations continued to also purchase new draft horses and horse-drawn implements even after they had already started transitioning to tractor-drawn implements. For instance, an evaluation of purchase records during the first years of the Pendleton Station indicated that they purchased a new ½-ton Ford pickup truck in 1928, a new Caterpillar tractor (1929), a rod weeder with a tractor hitch (1929), a two-way four bottom plow with tractor hitch (1929), a 6-foot one-way disk with tractor hitch (1930), a Gleaner push-type combine to be mounted on the Caterpillar (1929), and a Ford Model T engine to operate the combine. In 1929 they also purchased a 'span' of [2] draft horses and a hay mower, 'farm truck', grain binder with bundle carrier, disk harrow with 18-inch disks, self-dump rake, corn drill and a two-way sulky plow, each set up to be pulled with two horses, including hitches with neckyoke, tongue, double trees and full sets of harnesses. On January 22, 1931, an order was placed for an "*International Harvester Company of America 11×7, Double Disc Grain and Fertilizer Drill, 3×3/16"-wide wood wheels, and 2-horse hitch, at $172.50 …*" The Station records therefore showed payments for parts and repairs for harnesses and horse hitches at the same time they were repairing the Caterpillar and buying fuel and lubricants, new tires and tubes, new radiator, fan belt and drive shaft for the pickup. At the same time they were buying photographic cameras, lens, tripods, film, an electric drill, a Monroe calculator, grain sacks, horse shoes, and rope. It was an era of tremendous transition, depending on the job and the capabilities of either horses or tractors for greatest efficiency or less cost at that time.

Massy-Harris self-propelled combine during its first use at the Sherman Station in 1944

The specific focus on equipment performance and design became amplified in the late 1940s when the USDA began deploying additional personnel and funds for research at the Pendleton Station. A principal objective was to develop equipment and tillage systems for managing stubble without burning the wheat straw. Topics of emphasis for research on equipment modification and design varied over time, depending upon the existing needs of the industry and the interests of the engineer. However, over time, equipment modification and design also became an important component of other scientists in addition to the agricultural engineers. Such activities were conducted by agronomists, soil scientists, plant physiologists, plant pathologists, wheat breeders and weed scientists. Selected examples of contributions are discussed in the following sections.

Harvesting a wheat field at the Sherman Station using a John Deere 36B combine, in 1944

Machinery Performance

During the mid- to late-1940s farmers and equipment dealers asked researchers for assistance in answering questions regarding conservation farming systems. The questions included the following. How useful is the present line of farm machinery for conservation farming? What implements are doing a job the way they should? What revisions are necessary in present equipment? What new machinery is necessary? Some old equipment, such as the skew treader, was making a comeback into "*this battle of mauling the mulches*." It was clear that equipment developed by farmers, technicians and manufacturers needed to be tested and compared in a systematic manner. Specific research on machinery performance became an expansive initiative at the Pendleton Station during the 1950s and early 1960s. A major objective was to evaluate and modify equipment to optimize the farmer's ability to efficiently practice the stubble mulch tillage system.

It was not a coincidence that major changes occurred in the staffing, structure and activities at the Pendleton Station during the late-1940s. The initial change of importance was a USDA-mandated transfer of George Mitchell back to the Sherman Station and a reciprocal transfer of Merrill Oveson to the Pendleton Station. The USDA would not make intended new investments unless the program leadership was aligned in the manner the USDA thought to be essential. The OAES complied by switching the leadership of the stations during late-1948. Oveson, as Superintendent of the Pendleton Station, also became the Project Supervisor for the upcoming Columbia Basin Soil Erosion Project, which was a cooperative project between the Research Division of the USDA-SCS, the Soils Division of the USDA-BPI, and the OAES. Oveson was provided additional technical assistance through the appointment of a Carroll H. Ramage, a research assistant, that was jointly funded by the OAES and the USD-BPI. Also during 1949, Theodore R. Horning was appointed as the Agricultural Engineer for the Erosion Project, with funding being supplied by the Research Division of the USDA-SCS. In 1952, the administration of tillage-related research was transferred from the SCS to the Division of Soils, Fertilizer and Irrigation in the USDA-BPI. Shortly thereafter, in 1953, the USDA-BPI was restructured and renamed the USDA-Agricultural Research Service. The Erosion Project scientists received guidance from an advisory committee composed of farmers, representatives of agricultural organizations, and Merrill Oveson.

The changes in personnel at the Pendleton Station during 1948 and 1949 coincided with establishment of the 'Pilot Farm System' of off-station research facilities near Pendleton. The Pilot Farms were research sites with long-term leases on commercial farms; the Lester King Farm west of Helix, the James Hill Farm west of Helix, and the Sam Crow Farm southwest of Weston (see Chapter 5). Those three leases encompassed 323 acres of additional land that became maintained and farmed by staff at the Pendleton Station for the next 10 to 15 years. The pilot farm system was terminated in 1964, which coincided with Horning's retirement.

The increasing number of staff members at the Pendleton Station created a shortage of office space. That issue was overcome when the Oregon Wheat Commission provided $23,000 to build an addition onto the existing office building, convert the entire basement of that building into a soils laboratory, and construct a new seed storage and cereals laboratory building as an extension of the existing mechanical shop and equipment storage building. That construction occurred during 1954.

The following is a synopsis of equipment performance tests and modifications that occurred during research at the pilot farms.

King and Hill Pilot Farms

Identical tillage experiments were established on the Hill and King Pilot Farms. Data on each phase of the rotation could therefore be collected every year (see Chapter 5). Large numbers of samples were collected from incremental soil depths to determine moisture and nitrate content.

One experiment on the Hill and King Farms included 30 treatments replicated three times, with five fall tillage treatments that each crossed six spring tillage treatments. However, many decisions had to be made as to how best to manage the high volume of straw produced the previous year. The decisions had to be made each year, depending on the weather and the crop productivity in individual treatments. 'Practice' plots were established near the main experiment to allow the workers to adjust their equipment before moving it into the main experimental plots. The scientists came to consider those 'practice' plots to be an invaluable part of the experimentation, in that it allowed them to reduce or eliminate poor performance of each implement before using it within the experimental area.

Another experiment compared three types of seed drills, including a double-disk type with 7-inch row spacing, a semi-deep single-disk type with 10-inch row spacing, and a deep-furrow type with shovel openers at 14-inch row spacing. Different rates and types of fertilizer applied to fallow were also studied. One study compared four rates of anhydrous ammonia applied into trashy fallow. Another fertilizer study compared equivalent rates of anhydrous ammonia and ammonium nitrate.

Results of selected studies associated with this research to improve equipment were discussed in chapters relating to tillage systems, crop rotations, fertilizers, and weed control. An overall summary of the research to optimize the stubble mulch tillage system was published by Horning and Oveson (1962). That bulletin provided a complete discussion and illustration of soil erosion in the Pacific Northwest and of erosion control by high-residue management systems. It showed images of soil destruction by both water and dust erosion, and aerial images of successful control of erosion by strip cropping across steep slopes. The bulletin also shows images and discusses applications of most types of equipment required to prepare these soil-conserving practices. Many of the illustrations were from research trials conducted on the Pendleton Station and the King Pilot Farm. The authors provided a listing of 10 important factors considered essential for successful stubble-mulch farming in a wheat-fallow system, based upon experiments with these systems over a 10-year period.

The intensity of investigations on the King and Hill farms was illustrated by the preparation of separate annual reports for the Erosion Project. Exceptional details were provided. For instance, the 1952 Annual Report for the Erosion Project consisted of 191 pages filled with tables of data and summaries. The report included 50 pages devoted to 'Machinery Performance in Conservation Farming.' Detailed evaluations were provided for implements such as the following:

1. Edwards Culti-Cutter; to cut straw into shorter lengths and then waffled into the soil.
2. Gooley spring-tooth cultivator; to prepare seedbeds for both wheat and peas, and to apply anhydrous ammonia. The discussion included strength of the frame and angle of hitch.
3. Moldboard plow. The discussion included optimal width, hydraulics for depth control, and other aspects of the design.
4. Two-way plow; the manufacturer needed to refit it with a new style of hitch to improve its performance, but more revisions were still needed.
5. Stubby moldboard; they replaced the plowshares with steel plates to leave more stubble on the surface.
6. Cheney Soilivator; this is a sweep to take care of weeds after harvest. It needed to be modified to provide greater clearance for handling heavy straw on these farms.
7. Offset disks; they compared several different types of offset disks.
8. Calkins rotary rod weeder; they made only minor modifications to this implement.
9. Dunham rotary hoe; the rotary hoe is useful for leveling soil after rod weeding or where the ground is too hard or cloddy for a seedbed.
10. Dunham skew treader; this old implement was making a comeback particularly in areas where skew treading is more useful than rod weeding to reduce cheatgrass.
11. Wood rotary cutter is a stubble buster that breaks down, chops or shatters heavy stubble; no refinements were needed.
12. Calkins rotary subsoiler; the subsoiler is used after harvest to break up plow pans or hardpans, and used on hillsides to improve penetration of winter moisture. Improvements were needed.
13. McCormick No. 3 stubble carrier; this is a frame with tool bars that can be fitted with a range of different tillage implements, as a means to reduce the cost of buying individualized units of equipment. Its disadvantage was found to be the amount of time required to make changeovers between tillage operations.
14. John Deere combine leveler. They initially tested seven different types of levelers and determined that all of them lost a significant amount of grain while harvesting steeper slopes. In 1952 they started testing an automatic leveling model designed by John Slosser of the Research Division of the USDA-SCS, in Spokane. The John Deere Company quickly purchased and started manufacturing Slosser's design for the automatic leveler. Slosser was subsequently transferred to the Pendleton Station for a period of three years (1955 to 1957), where his mission was to lead a new research initiative sponsored by the USDA-ARS. His focus included perfecting the performance of his (now John Deere's) automatic leveling device, and developing more efficient tillage methods and equipment to meet the needs of agricultural practices in the Pacific Northwest. Slosser's leveler was mounted onto a self-propelled combine which was tested at the King and Hill Pilot Farms. Multiple problems were discovered, and Slosser made those engineering refinements.
15. Over multiple years, the use of the deep-furrow drill produced greater yields than the disk-type drills.

Crow Pilot Farm

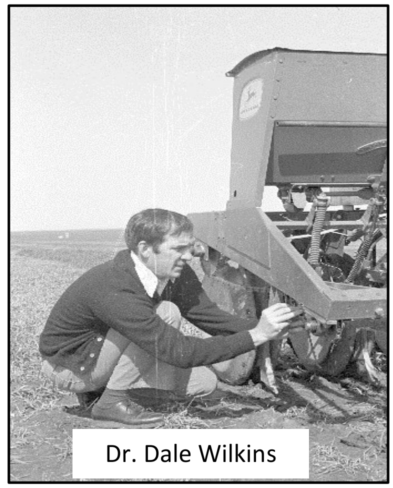
This farm was in an annual cropping zone. Nine tillage practices were examined for use in a wheat-green pea rotation. The scientists also examined a rotation in which sweet clover was planted with the peas and then, after pea harvest, the sweet clover was plowed the following year at three stages of growth (1- , 2- or 3-feet high) and with two types of plow (moldboard or sweep). They also tested three types of wheat drills that were described for the King and Hill Pilot Farsm. Other trials were on fertilizer application rates for wheat after peas, peas after wheat, and a comparison of anhydrous ammonia versus pea vines as a fertilizer. There was also a recropped winter wheat study with four rates of fertilizer application. As at the King and Hill Pilot Farms, great numbers of soil samples were collected in 1-foot increments to a depth of six feet for analysis of soil moisture and nitrate concentrations. Results of selected studies were discussed in Chapter 12.

Mechanical Innovations for Machinery

The first locally-based agricultural engineer (Ted Horning) retired in 1964. The next engineers to be stationed at Pendleton focused on documenting soil erosion during the late 1970s; Dr. Clarence E. Johnson (1977-1979) and Gerald O. George (1978-1980). More recently, engineers who focused on equipment performance and design included Drs. Dale E. Wilkins (1979-2003) and Mark Siemens (2003-2008).

Wilkins and Siemens examined and modified a wide-range of equipment used to produce field crops in eastern Oregon. They also developed collaborations with other scientists to establish multi-disciplinary teams who could work to overcome a number of specific constraints to farm productivity, profitability, and sustainability of the soil and water resources. The productivity of Wilkins and Siemens is shown by the high number of collaborative projects in which they became engaged, by the patents they were awarded for designs of new equipment components, and by the large number of publications they produced (Appendix 3).

Examples of long-lasting and productive relationships that involved Dr. Wilkins also involved leadership from Dr. John Kraft, a USDA pea breeder and pathologist at Prosser, Washington. Together, Wilkins, Kraft and other scientists improved the productivity of peas in the wheat-pea annual cropping region. Wilkins also worked closely with fellow USDA scientists Dr. Betty Klepper, Ron Rickman, and Paul Rasmussen to quantify the efficiency of seedling establishment and grain yield when different seed drills and different configurations of drill components were used, and when different forms of wheat stubble management were applied to the previous crop. Wilkins also quantified the amount of grain lost from the headers of various combines, and particularly the newly-introduced Shelbourne Reynolds stripper header, which removes grain from the wheat head without cutting any of the straw. Another of Wilkins productive relationships was with Dr. Richard Smiley (Oregon State University). Those scientists studied tillage and crop management practices to control Rhizoctonia root rot of wheat and barley during a time when no-till farming systems were becoming increasingly popular.


Dr. Dale Wilkins

Dr. Wilkins also fabricated a tillage tool that succeeded in enhancing water infiltration into already frozen soil. A 22-inch long tillage shank was mounted onto a tool bar mounted on the back of a tractor. Mounted directly behind the shank was a ‘spider wheel’ Calkins rotary subsoiler. The shank created a narrow deep trench through as much as six inches of frozen soil. The spider wheel made pock marks that provided easy access for surface water to enter the tillage channel. This implement improved water infiltration and reduced soil erosion when spring rain occurs onto soil that contains a lens of frozen soil. Unless penetrated, that lens of frozen soil below the surface will prevent water from infiltrating and will therefore cause liquefaction of the soil at the surface, causing it to move downslope as sheet erosion.

Dr. Wilkins many other contributions also included modification of drill openers to increase the efficiency of seed drills for planting tiny canola seeds, modification of seed drill openers to precisely place fertilizer near but not in contact with wheat seeds during planting, and development of a residue management wheel to increase the efficiency of seed drills operating in soils with high amounts of surface residue remaining from the previous crop.

Dr. Siemens’ research and collaborations were similar to that of Dr. Wilkins. Siemens also designed, refined and patented a residue management wheel and he studied modifications to combine headers that could reduce losses of seed while harvesting chickpea. His research involved the shape and spacing of the guard fingers in front of the sickle bar, and the type of reel used for harvesting chickpea. Siemens also compared performances of seed drills for planting green peas, and the effect of residue management on the performance of no-till drills. Mark Siemens also developed a new grain harvesting system so that, in a single pass across the field, the grain could be harvested and segregated into different seed bins, while at the same time cutting the straw into specific lengths that would not interfere with the performance of a no-till drill.


Dr. Mark Siemens

Another of Siemens engineering contributions was in the refinement of herbicide sprayers. Spray systems in which the nozzles are activated individually only when they approach a living weed have been commercially available since the early 1990s. This technology reduced herbicide application rates by as much as 90 percent. However, the intermittent sprays were exceedingly difficult if not impossible for the tractor or sprayer operator to monitor, particularly in dusty fields. Siemens designed and tested sensors and a central monitor that showed the driver when each nozzle was actually spraying on a 40-foot boom equipped with Weedseeker® spray sensor units (Siemens et al., 2007). The 'trigger-on' alert array could be easily monitored to determine if individual nozzles had become non-functional other otherwise not performing as intended.

Drs. John Williams and Dale Wilkins, plus others, developed a residue management system named 'mow-plow.' The mow-plow system consisted of a single-pass in which inversion tillage was conducted by mounting a combine header on the front of a tractor, which was pulling a moldboard plow. The header was used to cut standing stubble and distribute it laterally to cover the soil plowed during the previous pass. The plow inverted and buried the remaining stubble, along with wheat crowns and weed seeds. Except for the final pass, the field is therefore plowed but covered again with straw to provide protection from erosion. In experiments, the mow-plow system was compared to tillage systems using the moldboard plow and the chisel plow. Simulated rainfall was then applied to the three tillage systems at three different intensities of precipitation. The chisel plow treatment was the most resilient for reducing erosion, and was followed closely by the mow-plow treatment. Compared to use of the traditional moldboard plow, the chisel plow and mow-plow system each delayed the amount of time before water started running off the soil surface (see Chapter 17). The two conservation practices also considerably reduced the amount of soil that eroded from the treatments (Williams et al., 2000). The authors emphasized the importance of retaining straw at the soil surface to reduce soil erosion.

Mow-plow system. Stubble cut with a header is blown sideways onto freshly plowed soil. The moldboard plow behind the tractor inverts remaining stubble.

Soft-white wheat is produced to meet requirements for lower-protein products such as cakes, pastries, cookies, crackers and pocket breads. Marketing orders for soft-white wheat indicate a maximum protein percentage that can be included in the shipment; for instance, 10.5 percent. However, protein contents can be as variable as from 7 percent to 14 percent in fields with different profiles of soil moisture, soil depth, slope aspect, nitrate concentration, or other features. Drs. Dale Wilkins and Clyde Douglas observed that soft white wheat produced under dryland conditions had a high density when they had the lowest protein content, and a lower density when they had a higher protein content. That correlation did not always occur for wheat grown with supplemental irrigation. The scientists tested a gravity table to sort seeds from dryland fields by density, and therefore also by protein content. The system was found to be very successful for segregating grain lots into portions with low protein, which could potentially be sold at premium prices, and other portions containing the wide range of protein levels typically found in commercial shipments. They concluded that segregating grain with a gravity table could be scaled up for commercial application at grain storage and shipment terminals. Fifteen years later, in 1993, Dr. Mark Siemens and the Gilliam County Wheat Quality Laboratory reexamined and confirmed Wilkins and Douglas' findings.

Efforts to segregate wheat by protein content in real-time during harvest was greatly amplified at the Pendleton Station by the work of Dr. Dan Long and his research team during the first two decades of the 21st Century. Drs. Long and Mark Siemens, and John McCallum plus others, developed and refined equipment that could measure protein content of the combine's in-line grain stream during harvest. The sensing system was based upon the use of near-infrared reflectance spectroscopy (Long et al., 2008). They mounted the sensing equipment on the combine's clean grain filling auger and were able to rapidly analyze the grain protein content in the moving grain stream. This innovation opened the possibility for developing further options, such as directing grains of different protein contents into different grain bins. When it became possible to segregate protein contents during harvest, the scientists then evaluated whether that process would actually improve farm profitability. They determined that the process would be profitable for only a small percentage of farmers and individual fields under current market conditions.

In addition to research by the agricultural engineers, it was a common practice for other scientists and technical support staff to adapt, design and construct equipment to perform specific tasks. Drs. Don Wysocki and Christina Hagerty have each worked with commercial manufacturers to design and construct seed drills for use in experimentation. The work of Dr. Floyd Bolton in designing and testing the strip-till planting system was described in Chapter 13. Drs. Raymond Allmaras, Clyde Douglas and Paul Rasmussen demonstrated the improvement of tillage and planting operations by spreading the wheat straw and chaff as widely as possible when it flows out the back of the combine as grain is being harvested. Straw and chaff spreaders are now standard components of grain combines. Drs. Allmaras and others also devised a sampling method to determine the vertical distribution of coarse organic matter in soil profiles prepared by various tillage operations. This sampling facilitated quantitative descriptions of straw deposited at different depths by equipment such as the moldboard plow, offset disk, and subsurface sweep.

Several equipment innovations were made for weed control studies. Dr. Dean Swan designed and built a 2-wheeled plot sprayer for applying herbicides or fungicides in experimental plots. Dr. Arnold Appleby improved the performance of the plot sprayer by fabricating one with a single bicycle wheel, which made it easier to navigate through irregular surfaces such as deep-furrow plantings. Appleby's version included a motor-driven compressor and compressed air tanks. He then also designed and fabricated a 'logarithmic' plot sprayer. Appleby explained how it operated by stating: "*This sprayer works on the principle of constant dilution of the spray mixture with an accompanying decrease in rate. These particular plots were 100 feet long. The rate decreased logarithmically from the front of the plot to the back, with the rate at the end of the plot being 2.5% of the original rate. Evaluation was made by laying out a tape measure along the plot and noting the distance at which the crops and weeds were no longer completely killed, a distance at which 50% control or injury was estimated, and the point at which no control or injury was seen. With the use of charts, the rate of chemical applied at these points was determined. This information is given as LD_{100}, which is the lowest rate at which 100% control is obtained, LD_{50}, and LD_{0}.*" Dr. Don Rydrych then also developed a herbicide sprayer with a transparent tank for use on experimental plot sprayers, making it easier to determine the amount of solution remaining in the tank.

Plot sprayer to apply herbicides

Larry Baarstad designed and constructed a hydraulic soil sampler that could move through experiments with minimum disturbance to plants and soils. Paul Thorgersen designed and constructed a no-till drill with multiple capabilities for dispensing seed and multiple types of fertilizers or granular pesticides in experimental plots. Dr. Richard Smiley designed a tractor-mounted herbicide sprayer with shielded nozzles to kill weeds between wheat rows in experimental plots planted with a deep-furrow drill and 14-inch row spacings. Weeds between wheat rows could be killed as long as the wheat plants had not yet started to expand into the inter-row space.

In almost all cases, additional modifications to fabricated equipment were required to optimize their performance in doing the jobs for which they were designed. These types of equipment fabrication and modification procedures therefore clearly involved strong contributions and leadership by technical staff, including but not limited to such individuals as Wes Warn, Frank Ball, Gordon Fischbacher, Les Ekin, Daryl Haasch, Richard Greenwalt, Bob Correa, Larry Baarstad, Larry Pritchett, Alan Wernsing, Dave Robertson, John McCallum, Wayne Polumsky, Erling Jacobsen, Paul Thorgersen, Karl Rhinhart, and Steve Umbarger.

Strategic Site-Specific Innovations for Machinery

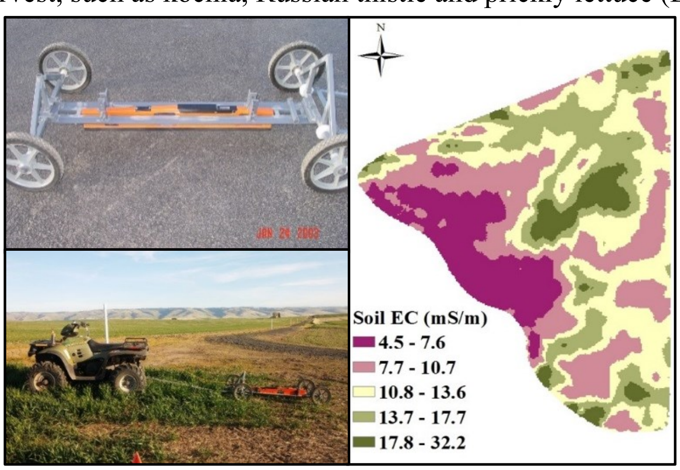
The foregoing sections addressed fabrication or modifications of the mechanical components of equipment used in agricultural research. Advances in efficiency and access to global positioning system (GPS) technologies created new opportunities to apply those systems to commercial agriculture. Precision technologies became an active and productive focus of agricultural research during the 21st Century. Numerous contributions from scientists at the Pendleton Station have already been recorded. Selected examples are discussed in this section.

Development of near-infrared sensors and equipment that segregated the grain stream within the combine according to different protein levels was discussed previously. Dr. Dan Long and his colleagues also successfully linked that equipment with yield monitors, light detection and ranging (LiDAR) sensors, and GPS receivers. The combination of those technologies were used to create maps that showed where different grain protein contents occurred within different portions of each field (Long et al., 2005, 2008). Although it had been determined that profitability of grain segregation by protein content during harvest was limited, it was likely that growers could reap economic benefits by reducing the overall protein variability across their fields and farms. It would be possible to use maps of protein variability across fields to apply different fertilizer levels to those areas to reduce the variability. For instance, when the maps were paired with GPS systems on tractors, nitrogen rates could be custom altered automatically (on-the-go) without the necessity to change the pattern in which tractors are normally operated across each field. The variable nitrogen rates are well suited for minimizing the variability of protein content across entire fields.

Drs. Dan Long and John Sulik with an octocopter for aerial imaging research

The use of GPS technologies to create maps of variability across fields opened the possibilities for many other innovations. One example is the remote sensing research that Dr. Jan Eitel contributed to Dr. Long's research program. Eitel developed ground-based and satellite-based wavelength reflectance sensing systems to estimate the nitrogen status of wheat crops (Eitel et al., 2007, 2008; and Long et al. 2009). Those systems differentiated reflectance from different concentrations and proportions of chlorophyll 'a' and chlorophyll 'b' in wheat leaves with allowance for variability in crop biomass and cover that is driven by plant water availability in dryland wheat fields.

Another application of these technologies was the use of multiple sensors mounted on grain combines to develop combinations of site-specific measurements of grain yield, grain protein, and straw yield at the same spatial resolution as grain yield (Long and McCallum, 2015). Grain yield was measured by a mass flow yield monitor, and grain protein concentration was measured with an in-line near-infrared spectrometer. An estimate of straw yield was determined by measuring crop height by using a LiDAR instrument. Information from combinations of these instruments could be used to identify areas within fields where grain yield was limited by nitrogen stress or water stress. A further improvement of this multi-sensing technology was through incorporation of an optical sensor to detect green plant material within the grain stream, denoting the presence of green weeds in the area being harvested. This technology was useful for mapping the distribution of weeds that were green at the time of harvest, such as kochia, Russian thistle and prickly lettuce (Barroso et al., 2017).



Instrument for mapping electrical conductivity, and a field map that correlates with soil depth

Dr. Stephen Machado estimated soil depth indirectly and rapidly by pulling an electrical conductivity-measuring instrument along narrowly spaced (100 feet) parallel paths across wheat fields. Yield maps along those same pathways were produced using geo-referenced sites. Electrical conductivity was well correlated with manual measurement of soil depth and grain yield (Machado, 2006). Measurement of the soil's electrical conductivity could therefore be used to identify different management zones within fields to increase or decrease inputs to improve profitability, compared to applying inputs uniformly across entire fields.

Drs. John Williams, Dan Long and Stewart Wuest determined that use of GPS technology to guide deep-furrow drills along single-elevation contours near the tops of slopes could reduce water runoff from the hillslope, increase infiltration, and reduce soil erosion (Williams et al., 2011). They used laser-leveling technology to determine the accuracy of GPS digital-elevation mapping software to guide the tractor pulling the seed drill. These scientists determined that, if at least two percent of the upper slope of the run-off collection area was contour seeded with that particular drill, that the procedure increased the amount of water captured and reduced the amount of soil eroded during a 100-year storm event over the course of 24 hours.

Equipment to Monitor Soil Tilth and Erosion

Scientists and technicians frequently faced the need to design and fabricate innumerable types of experimental equipment to monitor specific aspects of soil and plant properties under field conditions. A small selection of examples of non-machine types of equipment fabricated for use in field experiments is presented in this section.

Dr. Clarence Johnson (1977-1979) and Gerald George (1978-1980) were agricultural engineers at the Pendleton Station who focused on documentation of soil erosion characteristics across five counties in northcentral Oregon. Similar objectives became the responsibilities of hydrologists (Drs. John Zuzel, 1979-1995, and John Williams, 1995-present) who followed the earlier erosion-control engineers. Each of these individuals became involved in designing or configuring devices that were constructed in farmer's fields to quantify the amount of soil and water moving off soils that were managed with different types of tillage and different amounts of surface roughness and different amounts of residue incorporated or left on the soil surface. They utilized different configurations and types of recording and volumetric rain gauges to measure intensity and duration of rainfall, recording thermometers with sensors placed at various depths in soil, recording flow meters, sediment traps, and outflow samplers. A micro-relief meter was used in most studies of rill erosion. That device consisted of large numbers of small-diameter rods that were mounted on a backboard that was scribed to show elevations at the top end of all the rods. When the frame was placed over a soil surface and the rods dropped onto that surface, the tops of the rods revealed a topographical pattern that could be photographed and quantified for that particular transect of the field. In studies of erosion, this device precisely measured the depth and pattern of rill erosion on the surface of soils. The calculations of soil loss from rill cross-sections were often compared to the amount of soil collected by a sediment trap at the bottom of the slope. Several types of rill-measuring devices were also used for many other erosion and soil management studies. For instance, Paul Rasmussen and Dr. Clyde Douglas used the micro-relief meter to determine effects of rill erosion on growth and yield of winter wheat.

Micro-relief meters for quantifying soil cloddiness and rill erosion

Dr. Ron Rickman also used a micro-relief meter to quantify the irregularity of soil surfaces after various tillage practices. In addition, Rickman fabricated and refined a device that measured surface roughness and porosity without removing physical samples. In that way, samples could be taken repeatedly to estimate surface roughness stability under different tillage regimes. Rickman's device was based upon the reflection of sound from the soil surface. The equipment required use of an acoustical speaker, a pair of dynamic microphones, and equipment to record the frequencies of reflected sound.

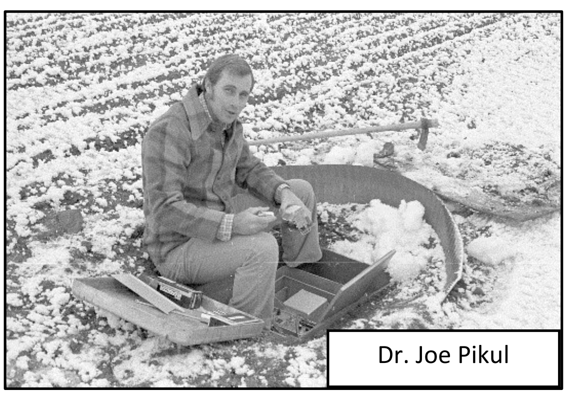
It was common to establish the erosion monitoring plots with various management treatments being oriented up and down the slope. However, for some erosion-monitoring experiments, it was frequently necessary to install borders between the various management plots to prevent cross flow from one treatment to the other. Physical barriers or ditches could often serve that need to separate the plots. However, for some experiments, the borders needed to be able to contain the flowing water but could not be installed by using a wheeled or tracked implement that would alter the soil surface and other properties along the edges of adjacent plots. Wes Warn and his research leader, Dr. Raymond Allmaras, designed a portable border installation device that was moved from one end of plots to the other end by using a winch on a vehicle parked at one end of the experimental area. That equipment was used for many erosion studies conducted by scientists at the Pendleton Station.

Reduction of soil erosion is often achieved by manipulating the placement and depth of crop residues in soil. It is generally straight forward to estimate the amount of surface residue but is much more difficult to quantify the spatial distribution and amount of residue under the soil surface. Dr. Allmaras and colleagues developed a method to estimate amounts of incorporated crop residue by measuring soil bulk density, incorporated coarse organic matter, and organic carbon in segments of incremental depth samples collected from soil cores (Allmaras et al. 1988). The method could distinguish among different methods of primary tillage and could also distinguish between effects of primary and secondary tillage practices.

Drs. John Williams and Dale Wilkins, plus others, fabricated a rainfall simulator for use in erosion control studies. The 'Pacific Northwest Rainfall Simulator' produced 'rain' at five discrete intensities applied individually over four adjacent 5 × 30 foot plots. The frame provided support for screens that prevented interference by wind, and to also support instruments for recording temperatures of air and water during 'rain' events. This simulation equipment produced accurate and precisely-controlled rainfall events at temperatures as low as 22ºF (Williams et al., 1998).

Dr. Stewart Wuest designed a temperature measuring instrument that could be driven into the soil by using a mallet. The instrument was designed to measure and record real-time temperatures of the soil profiles for extended periods of time, without introducing errors that are common when sensors are inserted by digging and backfilling a trench. The instrument was very useful for precisely measuring temperature variations and trends at about ½-inch depth intervals under various tillage management practices. The basis of the device was the attachment of thermistors to a circuit board and then stiffening and protecting the electronics with plastic wrappings. A multiplexer and data logger were used to measure and record temperatures repeatedly at the various depths.

Research on soil properties typically requires the collection of soil cores to a precise depth. Cores are then sectioned into increments varying from ½- to 6-inch to examine the properties of interest at each depth interval. The sections usually must be precisely divided without mixing and without destruction of the soil structure. This task can become tedious and time consuming. Several improvements for collection of incremental depth samples have been designed and fabricated by scientists at Pendleton. The first generation of improvement was by Drs. Joe Pikul and Raymond Allmaras during 1978. They modified a square-shaped soil sampling tube by cutting narrow slots at about ½-inch intervals across one face of the tube. They designed a cutting guide and a cutting blade that was inserted into the tube, severing in succession each depth increment of soil, which was then removed by inverting the tube. The sampler proved to be very useful particularly in summer fallow soils where the moisture content and cohesiveness of the soil profile varies greatly within each depth increment. Thirty years later, in 2007, Drs. Stewart Wuest and Bill Schillinger (Washington State University) greatly improved upon this type of sampling equipment. They produced a unit that mechanically pushed pre-specified lengths of soil samples from a round tube. The emerging soil was manually cut from the top of the tube and then an electrical signal was sent to push the next increment of soil from the tube. This unit greatly reduced the time for collecting incremental depth samples and also greatly reduced the variability that was often measured in side-by-side soil cores using previous sampling methods.



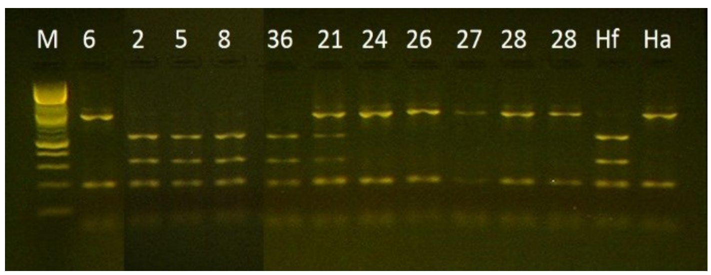
Dr. Joe Pikul

Equipment Modifications for Laboratories and Greenhouses

As with equipment for research in the field, scientists also constructed and modified innumerable types of equipment for research in laboratories and the greenhouse. Just a few examples are used to exemplify this point. Don George, a USDA plant physiologist was responsible for characterizing the cold tolerance of wheat varieties from 1954 until 1965. His work was in support of the wheat breeding programs of Drs. Orville Vogel, at Pullman, and Charles Rohde, at Pendleton. George needed to construct plant growth chambers in order to perform that research. During the mid-1950s he constructed a heavily insulated commercial-type meat locker facility in which one room could be regulated at below freezing temperatures and an adjacent room could be controlled at low- or near-freezing temperatures. Upon completion of that work, George and Dr. Charles Rohde modified the rooms to facilitate their use for stripe rust research under greenhouse conditions. Each of the three stages of the disease development have different temperature optima. One room was regulated at a cold temperature that favored germination of the pathogen spores and initial infection of the wheat leaf. After the leaves were infected, the plants were moved into the adjacent room that was maintained at a slightly warmer but still cool temperature to favor the pathogen's spread inside the leaf. When the leaves were well infected, the plants were moved into a greenhouse to favor further development of the disease.

After Rohde retired, the walk-in controlled temperature chambers continued to be used extensively for stripe rust resistance breeding by Dr. Pamela Zwer. She also used a slight variation of that temperature-transfer scheme to breed wheat for resistance to the Russian wheat aphid. The cold room facility was therefore used continuously for wheat breeding research for four decades, until there was no longer a resident wheat breeder at the Pendleton Station. For another two decades, until 2017, one chamber was used as a plant-growth room for Dr. Richard Smiley's research on root diseases, and the other room was used as refrigerated storage for large volumes of soil and plant samples.

Dr. Guiping Yan, a molecular biologist in Smiley's program, designed DNA-based tests to identify and quantify several species of nematodes that injure wheat roots. Smiley also designed an apparatus to separate nematode cysts from soil so they could be identified and counted. References to these tests and equipment are shown in Appendix 3.



DNA-based diagnostic test to distinguish the identities of two species of cereal cyst nematode in the Pacific Northwest

As in other chapters, the foregoing discussions shed only shallow insights into innovations created by the scientists and staffs at the Sherman and Pendleton Stations. Many additional examples of equal importance could have been cited.

References:

Annual Reports from the Sherman and Pendleton Stations (Appendices 4 - 6)

Letters sent to or from the Station Superintendents

Allmaras, R. R., J. L. Pikul, Jr., J. M. Kraft, and D. E. Wilkins. 1988c. A method for measuring incorporated residue and associated soil properties. Soil Science Society of America Journal 52:1128-1133.

Barroso, J., J. D. McCallum, and D. S. Long. 2017. Identifying weed infestations with optical data at harvest. Sensors 17:1-17.

Eitel, J. H., D. S. Long, P. E. Gessler, and E. R. Hunt, Jr. 2008. Combined spectral index to improve ground-based estimates of nitrogen status in dryland wheat. Agronomy Journal 100:1694-1702.

Eitel, J. H., D. S. Long, P. E. Gessler, and A. S. Smith. 2007. Using in-situ measurements to evaluate new RapidEye™ satellite series for prediction of wheat nitrogen status. International Journal of Remote Sensing 28:4183-4190.

Horning, T. R., and M. M. Oveson. 1962. Stubble Mulching in the Northwest. USDA Agriculture Information Bulletin No. 253. US Government Printing Office, Washington, D.C., and Oregon Agricultural Experiment Station, Corvallis, Oregon. 28 pages.

Long, D. S., J. U. H. Eitel, and D. R. Huggins. 2009. Assessing nitrogen status of dryland wheat using canopy chlorophyll content index. Plant Management Network. Online at doi:10.1094/CM-2009-1211-01-RS.

Long, D. S., R. E. Engel, and F. M. Carpenter, F. M. 2005. On-combine sensing and mapping of wheat protein concentration. Crop Management; on-line at doi:10.1094/CM-2005-0527-01-RS.

Long, D. S., R. E. Engel, and M. C. Siemens. 2008. Measuring grain protein concentration with in-line near infrared reflectance spectroscopy. Agronomy Journal 100:247-252.

Long, D., and J. McCallum. 2015. On-combine, multi-sensor data collection for post-harvest assessment of environmental stress in wheat. Precision Agriculture 16:492-504.

Machado, S. 2006. Demarcating management zones for site specific farming using electromagnetic induction and yield maps in eastern Oregon. Crop Management Journal. Online publication: http://www.plantmanagementnetwork.org/sub/cm/research/2006/zones/SiteSpecific.pdf

Siemens, M. C., D. E. Hulick, and B. Jepsen. 2007. Development of a trigger-on indicator for a weed sensing spray unit. Journal of Applied Crop Science (on-line) doi:10.1094/CM-2007-0515-01-BR.

Williams, J. D., D. S. Long, and S. B. Wuest. 2011. Capture of plateau runoff by global positioning system-guided drill seed operation. Journal of Soil and Water Conservation 66:355-361.

Williams, J. D., D. E. Wilkins, C. L. Douglas, Jr., and R. W. Rickman. 2000. Mow-plow crop residue management influence on soil erosion in north-central Oregon. Soil and Tillage Research 55:71-78.

Williams, J. D., D. E. Wilkins, D. K. McCool, L. L. Baarstad, B. L. Klepper, and R. I. Papendick. 1998. A new rainfall simulator for use in low–energy rainfall areas. Applied Engineering in Agriculture 14:243–247.

Chapter 15 - Soil Chemistry and Quality

In a speech at a meeting of the Eastern Oregon Wheat League, at Condon, OR during 1939, David Stephens, departing superintendent of the Sherman and Pendleton Stations (1912-1938), provided the following observations that are still pertinent in 2020. They provide an appropriate preface for this discussion of research on soil quality and soil chemistry.

> *"The idea of soil conserving practices for eastern Oregon is nothing new. About thirty years ago the late Governor James Withycombe, then director of the Oregon Agricultural Experiment Station, in numerous talks to farmers strongly advocated crop diversification, livestock raising, and the use of barnyard manure and legumes in eastern Oregon. A little later C. L. 'Farmer' Smith, Agriculturalist for the Oregon-Washington Railroad and Navigation Company, repeatedly advocated crop diversification and the growing of corn on eastern Oregon dry lands. Prof. H. D. Scudder of Oregon State College has long believed in smaller farms and more diversification in this area, and especially in the growing of alfalfa and field peas for sheep and hog pasture. In Oregon Experiment Station Bulletin No. 119, published in 1914, he stated that 'diversified production on the eastern Oregon dry farming lands is possible, has long been known, fully proved and earnestly preached in every section of the territory that the Experiment Station could reach.' Several Moro station bulletins have pointed out the desirability and possibility of crop diversification in this area. Notwithstanding all this, farm holdings have become larger and the farmers generally have continued the practice of growing only wheat. This doubtless has been due largely to economic considerations and in some instances to personal preferences."* (Stephens, 1939)

Today, farmers and scientists continue to examine the needs stated by the early scientists such as James Withycombe, 'Farmer' Smith, Harry Scudder, and David Stephens. Recently, in the driest production zones within the eastern Oregon wheat belt, farmers asked Pendleton-based scientists to coordinate on their farms a region-wide study of companion crops that could help to improve soil quality without extracting enough water to adversely affect the following wheat crop. Some of the farms hope to include livestock grazing as a component of that research.

Research at the Sherman and Pendleton stations have included studies that are fundamental components of the nitrogen and carbon cycles. The nitrogen cycle includes phases such as 1) application to the land of nitrogen fertilizer produced by industrial fixation, 2) biological fixation of inorganic forms of nitrogen into animal and plant proteins, 3) mineralization of plant and animal proteins into inorganic forms of nitrogen, 4) volatilization of denitrified inorganic or organic nitrogen into the atmosphere, 5) nitrogen leached below the root zone primarily in sandy soils, and 6) nitrogen carried by soil erosion into streams.

The carbon cycle refers to the exchange, or 'flow' or 'cycling' of carbon among the oceans, atmosphere, ecosystem (living organisms including plants, animals and microbes), and geosphere (solid components of the earth, including the fossil fuels and carbonate rocks such as limestone). Any change that shifts carbon out of these four 'reservoirs' puts more carbon into one or more of the other reservoirs. Changes that put carbon gases into the atmosphere result in warmer temperatures on Earth. Carbon is the principle structure of molecules essential for all living things and is the most important element for many chemical processes.

There are four processes of the carbon cycle that are of great importance on agricultural land: photosynthesis, decomposition, respiration and combustion. Photosynthesis by plants and by photosynthetic algae and bacteria convert energy from sunlight to combine carbon dioxide from the atmosphere with water to form carbohydrates. These carbohydrates store energy and the by-product, oxygen, is released into the atmosphere. Respiration by animals and plants releases carbon dioxide that was formed during aerobic respiration. When the animals and plants die, respiration by decomposers returns the carbon to the atmosphere as carbon dioxide.

After David Stephens published the above-quoted observation, scientists at the Sherman and Pendleton Stations have continued to conduct extensive research on issues relating to soil nitrogen, soil fertility, minor nutrient availability, fertilizer-use efficiency, mineralization of organic nitrogen, soil acidification, development of silica-enriched layers, soil carbon sequestration, carbon dioxide emission from soil, depletion and accumulation of soil organic matter, and a wide range of issues relating to soil quality. Research on these topics has resulted in more than 100 technical publications and book chapters, 15 extension bulletins and 66 local or regional extension reports (Appendices 3 and 4). This chapter summarizes results of some of that research. Aspects of this or related research were also addressed in chapters on the early history of the counties (Chapter 2), current experiments of historical importance (Chapter 6), crop rotation systems (Chapter 12), and soil microbiology (Chapter 19). Reviews have also been published by many of the scientists at the dryland stations, as well as in assessments published by others, including Barnett et al. (1995), Horner et al. (1960), Kok (2007), and Kok et al. (2009).

Soil Nitrogen

Nitrogen investigations became a topic of research soon after the Sherman Station was established. Measurements in treatments of rotation and tillage experiments were became critical because it had been demonstrated before the station was established that nitrogen and humus in the soil had been progressively declining with increasing years of crop production. Monitoring of nitrogen in the tillage and rotation experiments began in 1920. Nitrogen in the profiles of crops and fallow of numerous treatments have continued to be monitored throughout the histories of both dryland experiment stations.

In the summer of 1921, Professor J. S. Jones and George Mitchell collected samples of virgin and cropped areas in Sherman County to determine what change had taken place in the plant nutrients of soils due to cropping with wheat for the past 25 to 35 years. The soils were generally cropped annually for the first decade but then were managed as wheat-fallow rotations. Samples were taken to 4-foot depth. The top two feet of cropped soils had 10 to 20 percent less nitrogen and phosphorus than the top two feet of virgin soil. Jones and Yates (1924) included the following statements among the conclusions from those investigations.

1. "*While the summer-fallow system is perfectly justifiable for this section, it must, in the very nature of things, result in the more or less rapid depletion of the soil's content of organic matter (low in amount to begin with) and of the several elements of fertility, particularly nitrogen and phosphorus*."
2. "*Since reasonable amounts of organic matter are essential for the maintenance of ... good tilth, ... there are questions in the minds of all interested regarding possible changes in present farm practice that have promise of arresting soil depletion if not of recovering lost fertility*."
3. "*In every instance, ... the first foot of cropped soil is lower in its content of organic matter which makes for good tilth and greater water-holding capacity than the adjacent virgin soil. For the most part the same statement holds true for the second foot*."
4. "*There is evident, too, a small but positive decline in the nitrogen content of these soils …*"

That early report by Professor Jones led to additional investigations to determine if any of the "*rotations on the Moro Station that were planned to arrest soil depletion are really accomplishing the desired end*." During the fall of 1932, all plots of the rotation experiment, which was established in 1911, were again sampled to a depth of six feet and with repeated samplings through the growing season. The goal was to determine nitrogen and organic matter, following the 1922 sampling by Jones and Yates (see Chapter 12) and reporting of the data during 1924 (Jones and Yates, 1924). In the 1932 Sherman Station Annual Report they concluded that "*No rotation can be considered outstanding in maintaining the nitrogen balance of the soil.*" There was average of 11 percent less nitrogen in soils of the rotation treatments, compared to values obtained using the same methods 10 years earlier, in 1922. The least amount of nitrogen loss was in the continuous pea treatment, but that treatment also had the least amount of soil organic matter of all the treatments. These samplings also showed a downward movement of nitrate with the water during the growing season.

Nitrogen analyses of the various tillage treatments and the rotations showed that there was as much as twice more nitrate in the fallow plots with 'good fallow' compared to 'poor fallow' plots. These differences corresponded to higher yields in the good-fallow system. They also showed that the poor growth of wheat on the 'poor-fallow' plots could be reversed by adding nitrate of soda fertilizer early in the early spring while the soil was still moist and there was still an opportunity for sufficient rainfall to move the nitrate down into the root zone. These observations showed that tillage of fallow was not only controlling weeds and conserving moisture, but was also favoring mineralization of nitrogen from the crop residue.

In 1944, it was noted that there had been no improvement in wheat yield after 22 years of a field trial in which there were routine additions of strawy manure or pea straw, instead of retaining the wheat stubble.

It was stated in Chapter 3 that a comparison of nitrogen and carbon concentrations in Sherman County during 1909 showed that wheat-fallow rotations were already revealing a reduction of organic matter and nitrogen in the upper soil profile when compared to soils from virgin grasslands. It was predicted that soil degradation due to farming would become even more distinct in the future. These comparative samplings were repeated at several times since that original report. For instance, in 1924 the percentage reduction between virgin sod and cultivated soil was 13 percent for carbon and 10 percent for nitrogen in the top foot of soil, and 16 percent for carbon and 15 percent for nitrogen in the second foot of soil (Jones and Yates, 1924).

During 1932, two virgin sods were sampled at the Sherman Station and at the American Legion Cemetery at Moro (‘Moro Cemetery’). Cropped soil in the top foot of soil just 30 feet from the virgin sod sampling sites contained 24 percent less nitrogen and 21 percent less soil organic matter than the virgin grasslands (1933 Sherman Station Annual Report). More recent comparisons will be discussed in the organic carbon section, later in this chapter.

<u>Earliest Soil Nitrogen Experiments</u>

1. Differences of nitrogen and organic matter between virgin (uncultivated) sod and cultivated wheat fields first occurred in Sherman County in 1899, a decade before the Sherman Station was established, and similar comparisons have been repeated since that time.
2. Large pot studies during the 1930s and 1940s showed that 83 percent more wheat could be produced on soil taken from virgin sod than from an adjacent soil that had been cropped for up to 50 years.
3. By 1932 it was determined that none of the rotations being tested could maintain the nitrogen in the soil, and that nitrogen was being released into fallow as straw was being mineralized.

Soil Fertility and Fertilizers

When the Sherman Station was established there was no information available about the influence of fertilizer elements on the performance of wheat crops. The first synthetic fertilizer experiment at Moro was established in 1916. Scientists applied different rates of phosphate fertilizer to determine if phosphorus additions could increase wheat yield or expedite the time of grain maturation. They found very little influence of added phosphate on either of these questions. Nevertheless, that became the first of hundreds of synthetic fertilizer trials conducted by scientists at the Sherman and Pendleton Stations. Those experiments were conducted on commercial farms throughout the region as well as on station lands.

The first year in which synthetic nitrogen fertilizers were tested at the Sherman Station was in 1917. That test examined nitrate fertilizer applications on yields of spring wheat. The fertilizer was applied to the surface on three dates; on May 25 shortly after seedling emergence, on June 20 when wheat was beginning to head, or on July 15 when wheat was fully headed. A lack of rain following May 24 greatly limited movement of the nitrogen into the root zone. However, the promising finding that grain yield was increased by 5 bushels/acre where sodium nitrate was applied on May 25 set the tone for future investigations of soil fertility decades before commercial synthetic nitrogen fertilizers were envisioned as being necessary for wheat production in the area.

Issues relating to soil fertility have therefore been examined almost continuously since the Sherman and Pendleton Stations were established. In the four decades from 1970 until 2010, scientists at the stations published 34 papers on responses of crops to fertilizers in the research center’s Special Report series (Appendix 4).

An observation of particular interest occurred during the early 1920s, when there was an intense and sometimes heated debate about a condition called yellowberry of wheat. The debate occurred both locally and internationally. Opinions of scientists and practitioners differed over both the cause and definition of yellowberry. At the Sherman Station, the occurrence of yellowberry sometimes differed as much as 50 percent between ‘good tillage plats’ and ‘poor tillage plats’. It also differed among rotations and the various tillage treatments, as well as among varieties. Yellowberry kernels generally contained several percent lower protein than regular kernels, all of which were classed as hard wheats at that time. This was therefore very important because the presence of yellowberry reduced the market grade and price of wheat.

Nitrogen analyses of the various tillage treatments and the rotations during 1924 showed that there was as much as twice more nitrate in the fallow plats with 'good fallow' compared to 'poor fallow.' These differences corresponded to higher yields and much fewer yellowberry kernels in the good fallow system. Scientists at the Sherman Station also showed that the poor growth of wheat on the 'poor fallow' plats could be reversed by adding sodium nitrate fertilizer early in the spring while the soil was still moist and sufficient rainfall was likely to move the nitrate down into the root zone. These observations led them to conclude that tillage of fallow was not only controlling weeds and conserving moisture, but was also favoring mineralization of nitrogen from the crop residue. Jones and Mitchell (1926) published their findings and concluded that "*…it is concluded that yellow berry – low-protein wheat – is the manifestation of nutritional disturbances resulting from insufficiency of nitrogen and other elements of plant food for adequately meeting the requirements of a normally developing crop*." Research at the Sherman Station therefore aided substantially in resolving an international debate regarding the yellowberry issue.

A 20-year experiment established in 1921 determined the effect of commercial fertilizer or barnyard manure application on yield and quality of winter wheat grown after summer fallow at the Sherman Station. Commercial fertilizer was initially applied the day before the wheat was sown on September 17 and manure was applied as a top dressing during the spring. Treatments included the per acre application rates of 150 pounds nitrate fertilizer, 200 pounds superphosphate, 100 pounds sulfur, 100 pounds nitrate plus 200 pounds superphosphate, 200 pounds superphosphate plus 6 tons of manure, and 400 pounds 'Beaver Brand Complete Fertilizer'. There were no significant differences in yields among the treatments. The non-treated check yielded 38.3 bushels/acre and all of the fertilizer treatments yielded between 40.3 and 45.5 bushels/acre. The experiment was modified at some intermediate time such that the inorganic fertilizers and manure each began to be applied at the same time during early March. Applications were made every other year when winter wheat was being grown. This system did not always work well. For instance, in 1939 the wheat stand was good and uniform going into spring. Fertilizers were applied during early March and were moved into the soil with the March rains. But there was little or no rain after mid-March, which led to considerable drought injury to the wheat growing in the fertilized plots. The wheat went into premature drought stress where nitrogen had been applied, and this was especially prevalent where the nitrogen source had been sodium nitrate. The least amount of drought stress occurred on wheat fertilized with sulfur, superphosphate, or no fertilizer.

An experiment was established at the Sherman Station in 1942 to determine if minor elements were deficient in the soil. This was prompted by the discovery of zinc deficiency and occasional response to sulfur in some soils near The Dalles. The experiment was conducted in 35 four-gallon earthenware crocks filled with 43 pounds of soil from the station. Crocks were weighed weekly to maintain a moisture content of 15 percent. Soybean was used as the indicator crop. There were no responses to the minor nutrients in that test.

By 1947, it became common to apply fertilizer to some of the wheat trials on the Sherman Station. The 1947 Annual Report indicated sulfur deficiency was corrected by applying 100 pounds of sulfur at the time of plowing and an another 100 pounds as a top dressing at the time spring wheat was being seeded. This report coincided with the first routine applications of 2,4-D herbicide on the Sherman Station, suggesting that the chemical era for agriculture became established in the region during 1947.

A number of fertilizer experiments were conducted at the Sherman Station during 1950 and 1951. All 10 nitrogen timing and nitrogen application rate treatments improved the yield of winter wheat, as compared to the control treatment which received no added nitrogen. Compared to the unfertilized checks, the yields were improved by adding 10 lb N/ac but adding higher rates up to 40 pound/acre did not provide statistically greater yields than the 10 pound/acre rate. No additional advantage occurred when potassium or phosphorus were also added. The difference among wheat yields was greater when the fertilizers were applied to fallow prepared by subsurface sweep than by disking or moldboard plowing.

The first use of anhydrous ammonia at the Sherman Station occurred in 1952, when this product was incorporated into the fertilizer experiments. For this experiment and demonstration, the application equipment, anhydrous ammonia and technical supervision were each contributed by The Shell Chemical Company.

In 1954, experiments at the Sherman Station showed that the date of applying nitrogen did not matter. Yields were essentially equal from a wide range of different application dates.

Tillage studies initiated at the Sherman Station in 1940 were continued through 1955, but the objective became focused on efforts to determine the value of nitrogen fertilizer in over-coming the depressing effect stubble-mulch fallow on wheat yields. These trials compared residue management using three primary tillage treatments; moldboard plow, disk, or subsurface sweep. Yields continued to be considerably higher in the plow treatment than in the others, even when nitrogen is applied. In 1953, the rate of nitrogen applied had been increased from the previous rate of 10 pound/acre to a new rate of 30 lb/acre. This rate increase resulted in a yield increase of 3 to 5 bushels/acre. In the fertilizer experiments, maximum yield increases had been obtained with 40 pound N/acre, but the influence of yearly weather variation was so great that a blanket recommendation could not be made. It became realized that fertilizer application rates had to be varied depending on considerations of soil moisture availability plus the likelihood of future rainfalls.

New types of nitrogen fertilizers were being constantly introduced into the commercial market during the 1950s. Growers needed guidance about the relative merits of the different sources, as well as the best application timing and method. Experiments were performed at the Sherman Station to provide that guidance. The Sherman Station also participated in fertilizer experiments conducted on 140 farms in Sherman, Wasco, Gilliam, Morrow and Umatilla counties from 1953 to 1957 (Hall, 1997). The trials were coordinated by A. S. Hunter, a USDA soil scientist at Corvallis. Those trials served as a basis for improving the nitrogen application recommendations for growers in Oregon's wheat belt.

During 1954, an experiment was established to respond to growers who were expressing an interest in the possibility of shifting their production to hard red wheat in response to the surplus of soft white wheat in the American market. The growers needed to know if they could attain the high protein percentages required to meet the standard for hard red wheat. Fertilizer trials were conducted in 1954 with rates of applied nitrogen up to 120 pound N/acre. But the protein increased up to 12.2 percent with increasing rates of N to 80 pound of added N/acre, and then protein didn't increase further. That protein level was not high enough for the grain to be used as bread flour. Higher rates of N reduced the test weight (market grade) of wheat produced. These results indicated that it would not be economical to apply fertilizer in an attempt to produce high-protein wheat in regions with conditions similar to those at the Sherman Station.

The growers then turned their interests to the possibility of producing durum wheat, due to newspaper stories about the loss of the durum crop in the mid-west from a rust epidemic. Durum had been grown during the early years of the Station and had been found to be unprofitable at that time. A small nursery of new durum varieties was grown in 1955. As had been shown during the 1920s, durum yields were again considerably lower than the yields in the wheat variety trials being conducted during the 1950s. The protein level in the durum was also too low to be used in commercial production.

In 1958, foliar applications of urea combined in a tank mix with 2,4-D were tested to determine the effects of combining the two applications during the spring at Moro. That experiment demonstrated that there was no negative effect from the tank mix, which meant the scientists could begin advocating advantages of labor savings that became possible with such tank mixes.

Five soils that had shown responses to phosphorus or sulfur during testing from 1953 to 1957 were collected in 1962 and brought to the Sherman Station for testing in the greenhouse at that location. The soils were from a wide range of locations from Wasco County to Morrow County. Various combinations of N, P, and S were applied to the soils in pots used to grow spring wheat. Strong differences were observed in plant growth and plant color. However, powdery mildew invaded the experiment and was particularly bad on the fastest growing plants that also had the deepest green foliage. It was virtually impossible to control the mildew in the greenhouse. The disease became so intense that there were no yield differences among treatments. The study was therefore continued as field trials at 12 locations distributed across the region. At all locations, nitrogen was the only fertilizer element that provided an increase in wheat yield during 1963. There was no responses to application of phosphorus or sulfur, but the scientists documented the extraction of more moisture from soils that had been fertilized with additional phosphorus.

There were many more multi-year fertilizer experiments at the Sherman and Pendleton Stations from the 1960s to the present. Several of these experiments compare combinations of dates of seeding and rates of nitrogen application, and types of nitrogen fertilizers at different dates of application.

Station scientists began at an early date to recommend ways that farmers could optimize wheat production by maintaining soil fertility. The first of those recommendations were written into annual reports from the stations, and presented verbally at grower meetings. However, publications focusing only upon recommendations of fertilizer application practices apparently did not occur until after experiments had been concluded during the 1950s. The first formal extension bulletins to describe fertilizer recommendations appear to have been published by Brown and Oveson (1957) and Hunter et al. (1957). Many recommendations were then made from results of studies by Station scientists such as Vance Pumphrey and Paul Rasmussen, and Drs. Bob Ramig, Floyd Bolton and Donald Wysocki. Those experiments focused mostly on the requirement of wheat for nitrogen but also included evaluations of potentially deficient elements such as phosphorus, potassium, sulfur, and various micronutrient elements. In Chapter 20, it was stated that studies of a disease symptom called physiologic leaf spot determined that the disease was of non-pathogenic origin and could be reduced, and grain yield increased, by applying a chloride fertilizer (Smiley et al., 1993). Additional studies by other scientists, and by agronomists in the research division of the McGregor Company, confirmed that chloride was deficient for wheat production in some areas, and that yields could be increased by applying chloride, even when wheat did not display the leaf spot symptom. Physiologic leaf spot was subsequently renamed 'chloride-deficient leaf spot' (Smiley, 2010). The most recent fertilizer recommendations from the dryland experiment stations were published by Drs. Wysocki, Lutcher and Petrie.

A graduate student of Drs. Valtcho Jeliazkov and Hero Gollany recently published detailed micronutrient evaluations for soils in several historically-important long-term experiments at the Pendleton Station. The experiments were described in Chapter 6. Santosh Shiwakoti made comparisons of zinc, manganese, boron, copper and iron for the perennial pasture, crop residue management, wheat-pea rotation, and tillage × fertility experiments that were established in 1931, 1931, 1940 and 1963, respectively. The analyses were conducted on soil, wheat grain and straw samples archived from samplings taken at 10-year intervals from 1995 until 2015. After 84 years, all tested micronutrient concentrations in all treatments of the crop residue management experiment had declined relative to the grass pasture (Shiwakoti et al., 2019c). The highest manganese concentrations in the residue management experiment occurred in the treatments in which animal manure or pea vines were added prior to each crop in the winter wheat-cultivated fallow rotation. However, even those treatments had at least 33 percent less manganese than in the pasture soil. Lowest boron concentrations occurred in treatments for which the stubble was burned, or where the soil was fertilized with organic materials (animal manure or pea vine). Highest boron concentrations within the residue management experiment were found in plots that had received synthetic nitrogen fertilizers at rates of 40 to 80 pounds of N/acre/crop. Zinc concentrations within the experiment were all lower than in the pasture, whereas copper concentrations were all higher than in the pasture. Zinc was lowest and copper was highest in the inorganic fertilizer treatments, which was presumed to be a reflection of increasing soil acidity known to occur in response to applications of synthetic nitrogen fertilizers (see next section). Among the residue experiment treatments, the animal manure treatment had a far higher concentration of zinc than occurred in other treatments, but even in the manure treatment, zinc was less than in the pasture.

Shiwakoti et al. (2019b) also reported that extractable zinc and copper concentrations in treatments of the long-term tillage × fertility experiment were approximately half of that in the perennial grass pasture. Manganese and iron were also lower in the wheat-fallow treatments than in the pasture. However, within the experiment, highest concentrations of extractable manganese in the harvested wheat grain occurred where highest rates of nitrogen fertilizer had been applied, which was again considered a reflection of soil acidification caused by applications of synthetic fertilizer. Micronutrient concentrations were also lower in the wheat-pea rotation experiment than in the perennial grass pasture (Shiwakoti et al., 2019d). There was no difference among the four tillage treatments of that experiment. Since 1965, the soil pH in the upper four inches of soil had declined more in the no-till treatment than in the other tillage treatments. The reduced pH and greater organic matter concentration in the surface layer of the no-till treatment were considered to have important implications for micronutrient availability in the wheat-pea rotation.

Macronutrient concentrations were also evaluated in several of the long-term experiments. For the tillage × fertility experiment, Shiwakoti et al. (2019a) reported that concentrations of phosphorus, organic carbon, magnesium and calcium were far less than in the perennial pasture; by 32, 34, 77 and 86 percent, respectively. The nitrogen concentration was higher in the disk than in the moldboard plow treatment, leading the authors to conclude that disk tillage with high rates of nitrogen fertilizer could reduce the rate of decline in macronutrients over time. Likewise, Shiwakoti et al. (2019f) reported that, for the wheat-pea rotation, concentrations of organic carbon, magnesium and sulfur were 28, 46 and 67 percent less than in the pasture. The no-till treatment had greater concentrations of organic carbon, sulfur, phosphorus and potassium than plots that were plowed. It was concluded that no-till was more beneficial than plowing with respect to maintaining macronutrients in soil over long periods.

Soil Acidification

Soil pH is a critically important soil property because it influences a myriad of biological and chemical activities in soil, including growth of beneficial organisms and plant pathogens, nodulation of legume roots, and nutrient uptake by crop plants. Before discussing soil acidity, it is important to describe several points about pH and the ways in which it is measured in soils. Small differences in soil pH are critically important because pH values are based upon a logarithmic scale. This non-linear scale occurs because 'pH' is the shorthand for 'potential of Hydrogen.' A soil with a pH value of 5.0 is therefore ten times more acidic than a soil with a pH of 6.0.

Small differences in pH values are also especially important because scientists and laboratories use variants of two common methods to measure soil acidity. The apparent pH revealed by those methods provide values that are different. Both methods are based upon soil suspended in a liquid. The common liquids are either water or a dilute solution of calcium chloride. The water slurry method produces apparent pH values that are 0.4 to 0.7 units higher than those for the calcium chloride method (Smiley and Cook 1972). For the Walla Walla silt loam at the Pendleton Station, the difference between methods is about 0.7 pH unit. Therefore, measurements on a single sample by different scientists or laboratories may reveal a pH of 6.0 or 5.3, depending on the solution used to create the soil slurry. This is important because a difference of 0.7 pH unit represents a seven-fold difference in acidity due to the logarithmic scale. The method used must be considered for interpretations because the methods are not directly interchangeable. The calcium-chloride slurry method is considered to be the most 'plant-realistic' measure of soil pH because it reduces the level of interference caused by the multitude of ions other than hydrogen in the soil solution. The water-slurry method is further complicated because there are two standards for that measurement; a 1:1 or a 1:2 soil-to-water ratio. These two water-slurry methods are considered approximately interchangeable because they reveal only minor differences in pH values (0 to 0.2 unit).

Most native sods in eastern Oregon had water-slurry pH values between pH 6.5 and 7.2 before they began to be converted for production of wheat during the late 1800s. Nitrogen fertilizers began to be routinely applied to wheat crops during the 1920s and 1930s. Rates of nitrogen application increased significantly during the 1960s following the release of semi-dwarf varieties Gaines and Nugaines (see Chapter 7). Those varieties had a higher yield potential and greater resistance to lodging, as compared to older varieties. However, for maximum productivity, the semi-dwarf varieties also required much more nitrogen than the older wheat varieties.

Dr. Raymond Allmaras and USDA colleagues at Pendleton were among the first to recognize that acidification (decline in pH) of surface soils was occurring as a response to long-term applications of ammonium-based fertilizers (Allmaras et al., 1978). That was occurring because four hydrogen ions (H^+) are released into the soil solution when microorganisms convert an ammonium molecule (NH_4^+) into a nitrate molecule (NO_3^-). Allmaras et al. reported that acidification of soil in the upper foot of soil was directly linked to the total amount of ammonium applied to soil over a 37-year period of time, from 1940 until 1977. They measured soil pH using the calcium chloride slurry method. In experiment where the nitrogen application rates for various treatments varied from none to 160 pounds N/acre, the top six inches of soil had acidity differences as much as 1.1 pH unit; from pH 5.9 with no fertilizer applied to pH 4.8-4.9 at rates of 80 to 160 pounds N/acre.

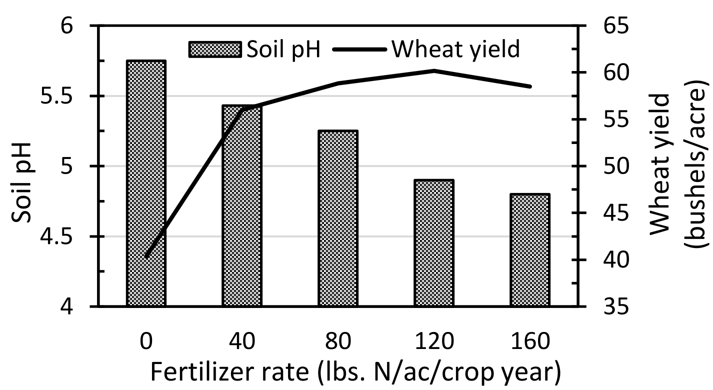
Allmaras et al. (1982) showed that soil in the long-term wheat-pea rotation and a nearby long-term wheat-fallow rotation at Pendleton were measurably acidified to a depth of 24 inches. The soils had pH values as much as one unit lower at the surface (pH 5.3 and 5.4, in a 0.01 M calcium chloride slurry) than at depths below 24 inches (pH 6.3). In comparison, the surface of a nearby native grassland had a surface pH only 0.2 pH unit below that at 24 inches. They estimated that more than two tons of lime per acre would be required to restore the most acidic soil surfaces to a pH value of about 6.2. That hypothesis was tested in the wheat-pea rotation. When soil was treated with lime, pea plants had more uniform germination and emergence, roots showed better nodulation and deeper penetration into soil, and there was as much as 14 percent better yield of the winter wheat crops that followed peas on limed soil (Allmaras et al., 1980)

Rasmussen and Wilkins (1987 and 1988) re-examined whether liming could improve the productivity of wheat or peas on the Pendleton Station. The upper six inches of cultivated soil in the tested fields had initial water-slurry pH values of about 5.9. Application of lime to those fields did not improve the productivity of wheat or peas. These results were consistent with findings of Mahler et al. (1985) and Mahler and McDole (1987). Mahler and colleagues reported that crops in northern Idaho did not respond directly to lime applications until the water-slurry pH values of surface soils become less than pH 5.5 to 5.7 for lentils and peas, less than pH 5.2 to 5.4 for winter wheat, or less than pH 5.2 for spring barley.

Rasmussen and Rohde (1989) again evaluated soil pH values in the long-term tillage × fertility experiment at Pendleton. That experiment had served as the basis for the earlier alert issued by Allmaras et al. (1978). The pH values reported in those two papers are directly comparable because both were based upon the use of the calcium-chloride slurry method. The research by Rasmussen and Rohde (1989) revealed pH values as low as 4.6 in the top three inches of disked or sweep-tilled plots that received a rate of fertilizer application (120 pound N/acre) that is common for higher rainfall regions in the area. These low pH values would have equated to pH 5.3 using the water-slurry method. This study was very instructive because Rasmussen and Rohde provided clear evidence that typical rates of nitrogen application in the Pendleton area had already reduced the soil pH to a value known to restrict productivity of peas and other legume crops and within the range that becomes limiting for productivity of wheat.

The same experiment at Pendleton was evaluated for a third time during 2010, seventy years after it had been established (Ghimire et al. 2017). The calcium chloride slurry method was again applied, consistent with the earlier samplings reported by Allmaras et al. (1978), and Rasmussen and Rohde (1989). Data presented by Ghimire et al. (shown in the chart) are nearly identical to those reported earlier. Surface pH values were as low as 4.5 in the sweep-tilled plot that received 120 pound N/acre prior to each crop in the wheat-fallow system. Values were from 6.3 to 6.5 in the second foot of soil under all three tillage systems; moldboard plow, disk and sweep tillage. The Ghimire et al. paper showed that 93 percent of the total nitrogen applied to the 'standard' fertilizer treatment (120 pound/acre/crop) had been applied during the last 42 years, since semi-dwarf wheat varieties began to be commercialized in 1962.

Dr. Don Wysocki demonstrated that samplings at depth intervals as small as 1½-inch could reveal even more troubling information regarding soil acidity. The zone of maximum acidity occurred at the depth where fertilizer is generally applied. In direct-drill (no-till) systems, fertilizer is repeatedly placed at the same depth below and/or between seed rows. Wysocki demonstrated that the zone of maximum acidity occurred at 5- to 6-inch depths in no-till systems, with water slurry pH values as low as 4.6 in Umatilla County and as low as 4.8 in Sherman County. These values would have equated to pH values of about 4.0 if the calcium chloride slurry method had been used. Surface-applied lime (>1 ton/acre) that was not incorporated into the soil did not immediately correct the deep-lying band of acidity.



Relationship between rate of nitrogen application, soil pH, and yield of winter wheat in a wheat-fallow rotation (tillage-fertility experiment) established at Pendleton in 1940 (from Ghimire et al., 2017)

Dr. Catherine Reardon, in cooperation with scientists at Washington State University, evaluated the stratification of soil chemical and microbiological properties at 2-cm (3/4 inch) depth increments in a no-till field that had received an application of surface-applied lime (Barth et al., 2018). The less-than-one-inch precision in depth sampling revealed high levels of stratification in pH, concentration of soluble aluminum, and composition of the microbial community. No differences in chemical or microbial properties were detected if the depth sampling precision was reduced to 4-inch increments. These scientists concluded that it would require about two years for surface-applied lime to cause detectable changes in soil properties at a depth of two inches in a typical no-till field in the Palouse region (24-inch rainfall zone).

Reardon and colleagues also compared methods to correct excess acidity by applying either biochar or hydrated lime. Both products were applied to the surface of a perennial grass seed field. The biochar was produced from residues remaining after the grass seed was harvested. Biochar applied at rates greater than eight tons/acre was more effective than hydrated lime for making rapid changes in pH of the surface soil (Phillips et al., 2018). The authors concluded that the seed farm could produce enough biochar to treat 10 percent of its acreage each year, which would enable that on-farm production system to be physically feasible as an on-going enterprise.

Nitrogen application rates are lower in Sherman County than in Umatilla County because of lower precipitation and lower crop productivity. The issue of potential soil acidification in Sherman County was addressed by Dr. Stephen Machado (unpublished data). Machado compared the acidity of soil under a virgin sod with soils under nearby cropped soils at a site 4.5 miles southeast of Moro during 2013. His pH measurements were made by using the calcium chloride slurry method. He collected soil from three sites within the pioneer-era Rose Hill Cemetery and five nearby fields. Four fields were managed as wheat-fallow rotations and one was in a long-term conservation grassland as part of the USDA-Conservation Reserve Program. Samples at all sites were collected from three 4-inch depth intervals to a depth of 12 inches, and from the 12- to 24-inch depth interval. The pH values in the top 4-inches of the virgin sods (pH 5.4 to 6.1) were 0.2 to 0.6 pH units lower than those in the second foot of soil (pH 5.9 to 6.3). In the cropped fields, acidification at the surface was greater (1.6 pH units) than in the virgin sods; pH 4.5 to 4.8 near the surface and pH 6.1 to 6.7 in the second foot of cropped fields. The top 4-inch segment of the CRP field had pH values within the same range as those for the virgin sods; pH 5.5 near the surface and 6.1 in the second foot of the soil profile. This research revealed that fertilizer-induced acidification is also occurring near the soil surface in low rainfall areas of Sherman County, although not to the same extent as in higher rainfall areas in eastern Umatilla County.

Silica Migration

USDA scientists at Pendleton were also the first to determine that soil pH was associated with the ability of water to infiltrate and move through profiles of silt loam soils. They made that discovery by investigating reasons why water infiltration in dryland farming areas of eastern Oregon and Washington is often restricted by a soil layer about 10 inches thick just below the tilled layer. The restricting layer reduces soil water storage by encouraging water runoff and erosion. The bulk density of the restrictive layer was essentially the same as for other soil layers during the spring, but resistance to a penetrometer became remarkably high at a depth of 10 to 12 inches when the soil was dry during the fall (Allmaras et al., 1982; Douglas et al., 1984). These observations are consistent with the development of a restrictive layer caused by cementation rather than compaction. The reduction in soil pH in the plow layer, caused mostly by the long-term application of ammonium-nitrogen fertilizers, encourages silica deposited as volcanic ash to dissolve and move downward as silicic acid. When the dissolved silica enters soil with a higher pH, the silica is redeposited and acts as a cementing agent.

Dr. Clyde Douglas and Paul Rasmussen using a soil penetrometer to determine the strength of a silica-cemented layer

Dr. Clyde Douglas determined that migration of silica out of the top foot of soil at the Pendleton Station was occurring under all management conditions but was far more pronounced where fertility needs were met by applying ammonium fertilizer than by applying pea vines or animal manure (Douglas and Allmaras, 1979; Douglas et al., 1984). Moreover, practices that increased the amount of soil organic matter reduced the amount of silica movement and reduced the strength of the cemented layer (Gollany et al., 2005 and 2006). Incorporating lime into the soil surface soil reduced the release of silicic acid from the upper six inches of soil. Additional geo-chemical studies at Pendleton were used to confirm the results of Douglas' earlier investigations (Baham and Al-Ismaily, 1996).

Organic Carbon and Organic Matter

It was stated earlier in this chapter that two virgin sods were sampled at two locations during 1932; the Sherman Station and the Moro Cemetery. Comparisons were made of cropped soils and virgin sods separated by a distance of only 30 feet. In the first foot of soil the cropped soils contained 21 percent less soil organic matter than the virgin grasslands (1933 Sherman Station Annual Report).

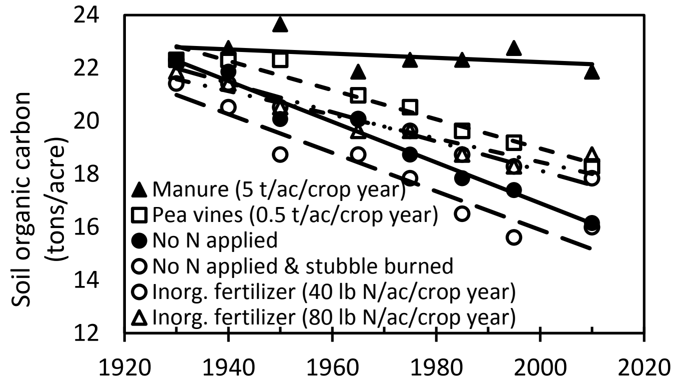
Soil organic matter was compared again for pairs of cropped vs. virgin soils at seven locations in Sherman County and five locations in Umatilla County during 1935. The loss of organic matter in cropped soil versus virgin soil averaged 16 percent in Sherman County (1.1 - 1.3 percent organic matter) and 26 percent in Umatilla County (1.5 - 2.0 percent). Virgin soil and cropped soil from these sites were placed into large open-topped barrels in 1936. The soils in the barrels were cropped and fallowed during alternate years through at least four crop cycles. During 1942, winter wheat produced 83 percent more grain in soil that had been virgin sod until 1936, compared to soil that was cropped as a wheat-fallow rotation for more than 40 years before the samples were collected in 1936.

Dr. Stephen Machado conducted additional comparisons of organic carbon under virgin sods and cultivated fields in Sherman and Umatilla counties during 2013. Sampling sites in Sherman County were at pioneer-era Michigan Cemetery (established 1887; 3.4 miles southwest of Grass Valley) and Rose Hill Cemetery (established 1885; 4.5 miles southeast of Moro). Sampling from cemetery sods was compared with samplings of nearby fields managed as high-residue winter wheat-fallow rotations and formerly cultivated field planted for several decades with grasses and forbs, in compliance with the USDA Conservation Reserve Program (CRP). The organic carbon content in the upper foot of soil was 29 percent lower in the cropped soils (0.8 – 1.1 percent) than under the virgin sods (1.3 – 1.4 percent). Samples collected in the cemeteries had 38 percent more organic carbon in the top foot of soil (>1.3 percent) than in the second foot (<0.9 percent). This difference was much less than that (42 to 57 percent) in samples collected from the cropped fields; 0.9 – 1.1 percent in the top foot versus 0.4 - 0.6 percent in the lower foot. Organic carbon in the CRP field was intermediate between that in virgin sods and cropped fields; 1.2 percent organic carbon in the upper foot and 1.0 percent in the second foot of the profile.

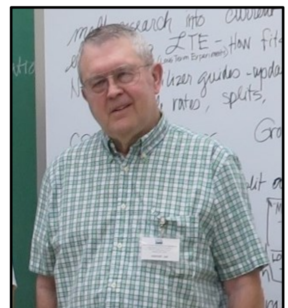
In Umatilla County, samplings were made at three locations; Vinson Cemetery (1869; 12.7 miles west of Pilot Rock), Pilot Rock Cemetery (1904; south Pilot Rock), and Greasewood Cemetery (1878; 4 miles northwest of Adams). Samplings near these sites included 15 winter wheat fields, 11 of which were managed as high-residue fallow and four managed as low-residue fallow. Organic carbon percentages in the upper foot of soil averaged 1.3 percent under virgin sods and 1.1 percent for cropped fields. Overall, the mean organic carbon content in the upper foot of soil was 19 percent higher for the virgin sods (1.1 – 1.6 percent) than the cropped fields (0.5 – 1.4 percent). There was little difference for carbon percentages (1.0 - 1.1 percent) in the top foot of soil for fields with different fallow management regimes. The average organic carbon in the 12- to 24-inch depth interval was similar for all samples; 0.7 percent in virgin sods and 0.6 percent in cropped fields.

Chapter 6 described a comprehensive crop residue management experiment that continues to be studied nearly nine decades after it was established at the Pendleton Station in 1931. The experiment is a 2-year rotation of winter wheat and cultivated fallow, using the moldboard plow as the implement for primary tillage. There are nine treatments that include different rates of nitrogen fertilizer, burning or not burning the wheat stubble, applying only animal manure or pea vines, or not applying any inputs at all. The history of those treatments is described in Chapter 6. Crop yields are measured annually and soil samples are collected for chemical and physical analyses at 10-year intervals. One of the major accomplishments has been documentation of the decline in soil organic carbon using wheat production practices most commonly encountered in the region. The following chart shows that, in a wheat-fallow rotation, the only treatment that came close to maintaining the concentration of soil organic matter found in virgin sods has been the application of animal manure prior to the planting of each wheat crop. The data supports findings from observations reported earlier in this chapter.

Scientists at Pendleton have published more than 40 peer-reviewed papers relating to soil carbon during the past two decades. They have also published five special reports on soil quality during the past two decades, 10 special reports on soil organic matter starting in 1924, and 3 special reports on carbon dioxide emission from soil. Those reports listed in Appendices 3 and 4 include papers from first authors such as Drs. Steve Albrecht, Raymond Allmaras, Rakesh Awale, Prakriti Bista, Stephen Del Grosso, Clyde Douglas, Jr., Bart Duff, Rajan Ghimire, Hero Gollany, Yi Liang, Mark Liebig, Stephen Machado, Paul Rasmussen, Ronald Rickman, and Stewart Wuest.



Changes in soil organic matter in the top foot of soil in a winter wheat-fallow rotation (crop residue experiment) established at the Pendleton Station in 1931

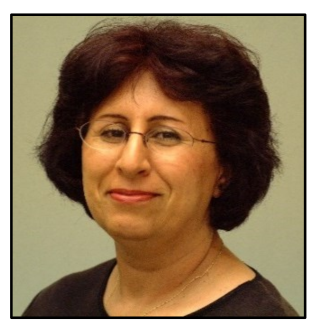


Dr. Clyde Douglas, Jr.

In 1992, USDA scientists at Pendleton published a model to describe the rate of decomposition of organic matter applied to soil (Douglas and Rickman, 1992). The model was named 'D3R,' in recognition of the developers, Douglas and Rickman. The model took into consideration the amount, timing and type of added organic residue, including roots, the timing and type of tillage, and the average soil temperature. The first public mention of the term 'carbon sequestration' at the dryland experiment stations occurred in 1999, when Drs. Albrecht, Douglas and Rickman addressed that issue and its underlying controversy in a Dryland Experiment Station Special Report (Albrecht et al., 1999).

Dr. Ronald Rickman

The concept of carbon sequestration became deeply embedded into the research philosophy at Pendleton when Rickman et al. (2001) published a new and refined model that estimated carbon sequestration in agricultural soils throughout the world. The name of the model was CQESTR, which was "*a liberal phonetic condensation of the word sequester*." During the past two decades, the concept of carbon sequestration has been a driving force for discussion of methods to mitigate the release of greenhouse gases, including carbon dioxide, which lead to changes in global climate. A great amount of recent research on that issue has been conducted at the Pendleton Station, primarily by Drs. Hero Gollany and Stephen Machado, and their colleagues that included a succession of post-doctoral scientists. For instance, the CQUESTR model has been calibrated so that it now provides responses that are almost identically to those for measurements of soil organic carbon analyzed directly on samples collected from the field (Gollany and Elnaggar, 2017).



Dr. Hero Gollany

Dr. Gollany's research focuses on effects of agricultural practices on soil chemical and physical properties, including processes that influence carbon and nitrogen dynamics and cycling. Her goal is to reverse the loss of soil organic matter and improve soil properties and productivity. She measured soil organic carbon and greenhouse gases in six cropping systems under various management conditions to determine which practices lead to highest carbon concentrations and the least greenhouse gas emissions (Liang et al., 2008). Dr. Gollany uses the CQESTR model to predict and evaluate the effect of residue removal on soil organic carbon. Her goal is to determine how much crop residue can be removed without jeopardizing soil organic carbon stocks and associated physical, chemical and biological processes. She coordinates her research at Pendleton with the USDA 'GRACEnet' (Greenhouse Gas Reduction through Agricultural Carbon Enhancement Network) program, which assesses soil carbon sequestration and greenhouse gas mitigation through agricultural management practices. Goals of that national network of scientists are to 1) evaluate the soil carbon status and direction of change of soil carbon in existing typical and alternative agricultural systems, 2) determine net greenhouse gas emissions (CO_2, CH_4 and N_2O) of those agricultural systems, and 3) determine the environmental effects (water, air and soil quality) of new agricultural systems developed to reduce greenhouse gas emissions and to increase soil carbon storage. Dr. Gollany's research has been reported in Appendix 3 by papers with first authors such as Drs. Stephen Del Grosso, Hero Gollany, Yi Liang, and Mark Liebig. Carbon dioxide emissions from experiments at Pendleton have also been reported by Drs. Stephan Albrecht and Stewart Wuest.

Collecting samples of soil air to quantify greenhouse gas emissions

Dr. Gollany's research indicated that only one cropping system could maintain soil organic carbon under the warming climate anticipated for the future (Gollany and Polumsky, 2018). That cropping system was continuousno-till winter wheat with a yield 30 percent greater than currently achieved. The intensification of cropping increased soil organic carbon stocks more than minimum- or no-tillage. Fallow continues to be a major impediment to maintenance of soil organic matter, which is required component of soil health and resiliency, resistance to drought, and protection of soil from wind and water erosion.

Dr. Machado's research focuses on agronomic properties associated with treatments of long-term experiments at the Pendleton and Sherman Stations. Many of the recent publications were published by the first authors Drs. Rakesh Awale, Prakriti Bista, Rajan Ghimire, and Stephen Machado. The previous chart, showing organic carbon decline in the crop residue experiment at Pendleton, was taken from the works reported by Dr. Machado. In a long-term experiment at Moro, Machado measured higher organic carbon concentrations in continuously planted plots (continuous winter wheat; continuous spring barley; winter wheat-winter pea; or grassland) than in plots that include a fallow period.

Wayne Polumsky in Chemistry Lab Dr. Stephen Machado

Dr. Hero Gollany collecting plant samples

References:

Annual Reports from the Sherman and Pendleton Stations (Appendices 5 and 6)

Letters sent to or from the Station Superintendents

Albrecht, S. L., C. L. Douglas, Jr., and R. W. Rickman. 1999. Carbon sequestration by agricultural soils. Oregon Agricultural Experiment Station Special Report 999:15-18.

Allmaras, R. R., K. Ward, C. L. Douglas, Jr., and L. G. Ekin. 1982. Long-term cultivation effects on hydraulic properties of a Walla Walla silt loam. Soil and Tillage Research 2:265-279.

Allmaras, R. R., K. Ward, and J. Kraft. 1980. Liming effects in a wheat-pea rotation - A progress report. Oregon Agricultural Experiment Station Special Report 571:73-77.

Allmaras, R. R., K. Ward, P. E. Rasmussen, and C. R. Rohde. 1978. Soil acidification from long-term use of ammonium-type nitrogen fertilizers. Oregon Agricultural Experiment Station Special Report. Pages 55-58.

Baham, J., and S. Al-Ismaily. 1996. Formation of weakly cemented siliceous pans induced by long-term agricultural management. Oregon Agricultural Experiment Station Special Report 961:68-70.

Barnett, V., R. Payne and R. Steiner (editors). 1995. Agricultural Sustainability: Economic, Environmental and Statistical Considerations. John Wiley & Sons, New York. 265 pages.

Barth, V.P., C.L. Reardon, T. Coffey, A.M. Klein, C. McFarland, D.R. Huggins, and T. S. Sullivan. 2018. Stratification of soil chemical and microbial properties under no-till after liming. Applied Soil Ecology 130: 169-177.

Brown, W. G., and M. M. Oveson, 1957. Profitability of fertilizing wheat in Umatilla County. Oregon Agricultural Experiment Station Circular of Information 583. 12 pages.

Douglas, C. L. Jr., and R. R. Allmaras. 1979. Silica movement in Walla Walla soils. Oregon Agricultural Experiment Station Special Report 547:22-23.

Douglas, C. D., Jr., R. R. Allmaras, and N. C. Roager, Jr. 1984. Silicic acid and oxidizable carbon movement in a Walla Walla silt loam as related to long-term management. Soil Science Society of America Journal 48:156-162.

Douglas, C. L. Jr., and R. W. Rickman. 1992. Estimating crop residue decomposition from air temperature, initial nitrogen content, and residue placement. Soil Science Society of America Journal 56:272-278.

Ghimire, R., S. Machado, and P. Bista. 2017. Soil pH, soil organic matter, and crop yield in wheat-fallow systems. Agronomy Journal 109:1-12.

Gollany, H. T., R. R. Allmaras, S. L. Albrecht, S. M. Copeland, and C. L. Douglas, Jr. 2006. Incorporated source carbon and nitrogen fertilizer influence on sequestered carbon and soluble silica in a Pacific Northwest mollisol. Soil Science 171:585-597.

Gollany, H.T., R. R. Allmaras, S. M. Copeland, S. L. Albrecht, and C. L. Douglas, Jr. 2005. Tillage and nitrogen fertilizer influence on carbon and soluble silica relations in a Pacific Northwest mollisol. Soil Science Society of America Journal 69:1102-1109.

Gollany, H. T., and A. A. Elnaggar. 2017. Simulating soil organic carbon changes across toposequences under dryland agriculture using CQESTR. Ecological Modelling 355:97-104.

Gollany, H. T., and R. W. Polumsky. 2018. Simulating soil organic carbon responses to cropping intensity, tillage, and climate change in Pacific Northwest dryland. Journal of Environmental Quality 47:625-634.

Hall, W. E. 1997. My Life in Moro with the Sherman Experiment Station. Sherman County: For the Record 15(1):17-29. Sherman County Historical Society, Moro, Oregon.

Horner, G. M., M. M. Oveson, G. O. Baker, and W. W. Pawson. 1960. Effect of cropping practices on yield, soil organic matter, and erosion in the Pacific Northwest wheat region. Washington, Idaho and Oregon Agricultural Experiment Station and USDA-ARS Cooperative Bulletin No. 1. Pullman, Washington. 25 pages.

Hunter, A. S., L. A. Alban, C. J. Gerard, W. E. Hall, H. E. Cushman, and R. G. Petersen. 1957a. Fertilizer needs of wheat in the Columbia Basin dryland wheat area of Oregon. Oregon Agricultural Experiment Station Technical Bulletin 57. 60 pages.

Kok, H. 2007. STEEP Impact Assessment. Report of a USDA Special Research Grant. Washington State University; on-line at http://cru.cahe.wsu.edu/CEPublications/EB2035Ea/EB2035Ea.pdf

Kok, H., R. I. Papendick, and K. E. Saxton. 2009. STEEP: Impact of long-term conservation farming research and education in Pacific Northwest wheatlands. Journal of Soil and Water Conservation 64:253-264.

Liang, Y., H. T. Gollany, R. W. Rickman, S. L. Albrecht, R. F. Follett, W. W. Wilhelm, J. M. Novak, and C. L. Douglas, Jr. 2008. CQESTR simulation of management practice effects on long-term soil organic carbon. Soil Science Society of America Journal 72:1486-1492.

Mahler, R. L., F. E. Koehler, and A. R. Halvorson. 1985. Long-term acidification of farmland in northern Idaho and eastern Washington. Communications in Soil Science and Plant Analysis 16 (1):83-95.

Mahler, R.L., and R. E. McDole. 1987. Effect of soil pH on crop yield in northern Idaho. Agronomy Journal 79 (4):751-755.

Oveson, M. M., 1966. Conservation of soil nitrogen in a wheat summer fallow farming practice. Agronomy Journal 58:444-447.

Rasmussen, P. E., and C. R. Rohde. 1989. Soil acidification from ammonium-nitrogen fertilization in moldboard plow and stubble-mulch wheat-fallow tillage. Soil Science Society of America Journal 53:119-122.

Rasmussen, P. E., and D.E. Wilkins. 1987. Winter wheat response to lime in a wheat-pea rotation. Oregon Agricultural Experiment Station Special Report 797:31-33.

Rasmussen, P. E., and D.E. Wilkins. 1988. Green pea response to lime in a wheat-pea rotation. Oregon Agricultural Experiment Station Special Report 827:43-45.

Rickman, R.W., C.L. Douglas, Jr., S.L. Albrecht, J. L. Berc, L. Norfleet, and M. Hobbs. 2001a. CQESTR, a field-level farm carbon sequestration planning tool. World Resources Review 13:356-368.

Rickman, R.W., C.L. Douglas, Jr., S.L. Albrecht, L.G. Bundy and J.L. Berc. 2001b. CQESTR: A Model to Estimate Carbon Sequestration in Agricultural Soils. Journal of Soil and Water Conservation 56:237-246.

Shiwakoti, S., V. D. Zheljazkov, H. T. Gollany, M. Kleber, and B. Xing. 2019a. Macronutrients in soil and wheat as affected by a long-term tillage and nitrogen fertilization in winter wheat-fallow rotation. Agronomy 9:178. doi:10.3390/agronomy9040178.

Shiwakoti, S., V. D. Zheljazkov, H. T. Gollany, M. Kleber, and B. Xing. 2019b. Micronutrients decline under long-term tillage and nitrogen fertilization. Scientific Reports 9:12020. doi:10.1038/s41598-019-48408-6.

Shiwakoti, S., V. D. Zheljazkov, H. T. Gollany, M. Kleber, B. Xing, and T. Astatkie. 2019c. Micronutrients in the soil and wheat: Impact of 84 Years of organic or synthetic fertilization and crop residue management. Agronomy 9:464; doi.org/10.3390/agronomy9080464.

Shiwakoti, S., V. D. Zheljazkov, H. T. Gollany, B. Xing, and M. Kleber. 2019d. Micronutrient concentrations in soil and wheat decline by long-term tillage and winter wheat-pea rotation. Agronomy 9:359. doi:10.3390/agronomy9070359.

Shiwakoti, S., V. D. Zheljazkov, H. T. Gollany, and B. Xing. 2019f. Effect of tillage on macronutrients in soil and wheat of a long-term dryland wheat-pea rotation. Soil and Tillage Research 190:194-201.

Smiley, R. W. 2010. Chloride and zinc deficient leaf spots. Pages 143-144. Compendium of Wheat Diseases and Insects, 3rd edition. (W. W. Bockus, R. L. Bowden, R. M. Hunger, W. L. Morrill, T. D. Murray, and R. W. Smiley, editors). APS Press, St. Paul, MN. 171 pages.

Smiley, R. W., and R. J. Cook. 1972. Use and abuse of the soil pH measurement. Phytopathology 62:193-194.

Smiley, R. W., W. Uddin, P. K. Zwer, D. J. Wysocki, D. A. Ball, T. G. Chastain, and P. E. Rasmussen. 1993. Influence of crop management practices on physiologic leaf spot of winter wheat. Plant Disease 77:803-810.

Stephens, D. E. 1939. Cultural practices for a more permanent agriculture in the Columbia River Basin. Pages 8-19. In: Proceedings of the 12th Annual Meeting of the Eastern Oregon Wheat League. Condon, OR. December 7-9, 1939.

Chapter 16 - Soil Water

Monitoring of weather and soil water began when each of the dryland stations were established. More detailed studies of soil and water conservation became possible when additional USDA soil scientists began to be hired at Pendleton. In 1940, Joseph Belanger was transferred from Moro to Pendleton. A succession of soil scientists followed, and soon began to include a succession of agricultural engineers, the first of whom was Ted Horning, in 1949. The presence of scientists with specific interests in soil water became significantly increased by the arrival of Dr. Bob Ramig, in 1961. About 10 USDA scientists with specific expertise in soil water were stationed at Pendleton before the USDA-ARS purchased land and established a new facility at that location, in 1970.

Scientists at the Sherman and Pendleton Stations have conducted research on all phases of the water cycle. They published at least 60 technical publications on water-related issues, in addition to innumerable extension papers and articles for the popular press. That research included studies of water infiltration into the soil profile, and on impediments to infiltration such as compaction, tillage pans, surface crusting, lack of earthworms, and soil freezing. Each of those processes affect the amount of water that runs off the landscape, the amount of soil carried in the runoff, and the volume and turbidity of streams and rivers. Some of the same principles affect the amount of dust that will become airborne when wind speed is high.

There are several essential processes that must occur in order for plants to utilize the limited moisture supply required for producing good crops in low rainfall regions. Farmers must increase the amount of water stored in the soil and reduce losses due to evaporation and transpiration. They must then also make maximum use of the stored water and additional precipitation by using production practices calibrated to the prevailing climatic conditions in each area.

Chapter 4 described the amounts and seasonal distributions of precipitation, and a computer model that enabled farmers to estimate rainfall in fields far from official monitoring stations. Chapter 18 described the amount of water required to germinate wheat seed. Measurements of water in crop rotation and tillage experiments were critical because maximum crop productivity in semiarid regions with dry summers is dependent upon efficient use of all available water in the soil profile. Much of the research on crop rotations, tillage, residue management, equipment design and soil quality were based upon the need to measure relationships with soil water, as was summarized in Chapters 12 - 15. This chapter includes studies of measures to increase the efficiency of water stored in the soil profile and of water extraction by crops.

<u>Earliest Soil Moisture Experiments</u>

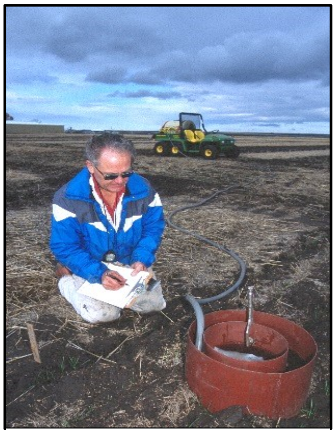
1. The first soil moisture investigation began at the Sherman Station in 1911. Large soil-filled pots were used to determine water-use requirements of wheat and alfalfa. Some of those studies continued until 1942.
2. The first comprehensive field test to monitor soil moisture occurred in 1919. The water content was measured at various depths under all treatments of all crop rotation and tillage experiments at Moro.
3. The first repetitive soil samplings to measure the rate of water extraction by winter wheat, throughout the crop year, began at Moro and Pendleton during 1932.

Water Infiltration into Soil

Water from rain, snowmelt or irrigation must enter into the soil and move downward in the profile before that water can become useful for sustaining plant growth. Water entry into soil is a complex process and has been the subject of extensive research at the Pendleton and Sherman Stations. Water enters the soil either as saturated or unsaturated water flow. When the precipitation intensity is relatively low and there is no ponding, the water moves into soil as unsaturated flow, which is governed primarily by attraction of water to dry solid surfaces (adsorption) and the surface tension of water held as menisci between solid surfaces. Adsorption plus capillarity produce the potential energy state of water, with water moving from areas of lower to higher matric energy potentials. The air-filled pore spaces that exist between solid surfaces is called capillarity. The rate of water flow along the solid surfaces is called unsaturated hydraulic conductivity.

Saturated flow becomes the dominant process whenever the water application rate exceeds the soil's unsaturated intake rate. This occurs when precipitation occurs at higher rates or over prolonged periods, or where water becomes ponded. Water intake under saturated flow conditions is called the infiltration rate, which is strongly influenced by soil porosity, soil water content at various depths, soil water permeability, and time. The maximum rate of saturated flow diminishes as water continues to replace air from the pores in soil.

Large pores near the soil surface are required for high rates of infiltration. Macroporosity is strongly influenced by soil texture, soil aggregation, and soil cracking. Aggregation and aggregate stability are governed by soil organic matter. Fragile aggregates disintegrate when they are wet or are impacted by raindrops. The breakage of aggregates allows individual particles of clay, silt or sand particles to be washed into the soil until they become trapped by very small pores in the underlying soil. At that point, the tiny particles create a consolidated layer that greatly impedes water flow whether it is wet or is dried into a crust. Surface crusting is a much greater problem in finely cultivated soils, particularly those with very low amounts of soil organic matter. Surface residues reduce or prevent crusting by reducing the physical forces that break small aggregates apart, such as the impact of raindrops, and cycles of freezing and thawing, and wetting and drying. Higher concentrations of soil organic matter helps to create stronger bonding of soil particles inside small soil aggregates.



Dr. Ron Rickman measuring the water infiltration rate

Water infiltration and storage was the primary consideration for much of the research on tillage, residue management, equipment design, and soil quality, as summarized in Chapters 13 - 15. This section discusses studies specifically designed to monitor infiltration rates and the factors that influence infiltration. These studies were conducted by USDA scientists Drs. Raymond Allmaras, Joe Pikul, Robert Ramig, Ron Rickman, David Stephens, John Williams, Stewart Wuest and John Zuzel, and by O.S.U. scientists Drs. Chengci Chen, Stephen Machado and Bill Payne.

A comprehensive study of water infiltration, internal drainage and evaporation was reported by Allmaras et al. (1982). They compared a wheat-fallow rotation at the Pendleton Station with a nearby commercial wheat-pea rotation and a nearby native grassland. They provided a formal description of each horizon in the cultivated Walla Walla silt loam, and reported the presence of tubular pores to depths of at least five feet, and the presence of fine roots even below that depth. Organic matter concentrations were greater in the top six inches and below 12 inches of the grassland soil than in cultivated soils, but the reverse occurred in the 6- to 12-inch depth segment. The soil bulk density increased with greater depths in the grassland and decreased with depth in the cultivated soils. These layering effects for organic matter and bulk density influenced the conductivity of water into and through the soil profiles. They also altered the relationship between water content and water potential, which differed not only on the basis of long-term management but also for each 4-inch depth increment. In general, cultivation reduced the hydraulic (water) conductivity in the upper eight inches of the soil profile. Cultivation also reduced the rate of water evaporation from the soil surface. The reduced rate of evaporation was assumed to have delayed the drying of the soil surface during the spring, resulting in a delay of optimal soil moistures for tillage during the spring.

Dr. Stewart Wuest demonstrating a measurement of water infiltration

Drs. Pikul, Zuzel and Ramig examined infiltration of precipitation over the winter after soils were either not tilled or were cultivated while dry during the autumn, using either a chisel plow or paraplow (Pikul et al., 1990). They studied total water storage, the porosity of the soils at various depths, and the final rate of infiltration during the spring. During the winter, the soils all stored the same amount of water to a depth of 10 feet. In March, there were very few (<1 percent) large air-filled pores (macropores) at any depth in the untilled soil. The chisel plow treatment contained 20 percent macropores at 3-inch depth and <1 percent at 12-inch depth. The paraplow treatment contained 17 percent macropores at 12-inch depth. The scientists concluded that the improved macropore structure developed by the two plow treatments during the autumn remained stable through the winter.

Drs. Joe Pikul, Raymond Allmaras and Chuck Rohde had performed earlier studies on water movement through tillage pans in various treatments of the long-term crop residue experiment at Pendleton, which was established in 1931, as described in Chapter 6. The experiment was managed as a winter wheat-fallow rotation, with moldboard plowing of all treatments during the spring following harvest. Pikul et al. (1983) showed that the tillage pan is the most restrictive soil layer governing water flow into the profile. They demonstrated that the bulk density of soil was greater in the upper 16 inches of soils where wheat stubble was burned during the autumn, as compared to a treatment on which animal manure was applied before each crop cycle. Tillage pans were present at depths of about 10 inches in both treatments, but the density of soil was much higher in the stubble-burn than the manure treatment. They also showed that water flow (saturated soil conductivity) was very slow through the both tillage pans at 8-inch depth (1-3 inches/day) compared to soil below the pans, at 14-inch depth (6 inches/day). The flow rate through the tillage pan was least in the stubble-burn treatment (1 inch/day) and highest in the manure treatment (3 inch/day). These results were consistent with findings of other studies (Rasmussen et al. 1978) that showed similar relationships with soil organic matter in those treatments of the crop residue experiment. Much of the tillage and equipment design research summarized in Chapters 13 and 14 had disruption of tillage pans as one of the objectives.

A decade later, Drs. Joe Pikul and John Zuzel measured influences of tillage, residue management and nitrogen fertility on water infiltration, again using the long-term tillage-fertility (since 1940) and crop residue (since 1931) experiments on the Pendleton Station. Both experiments were cultivated winter wheat-fallow rotations. In the tillage-fertility experiment, they found that water infiltration rates did not differ for soils that had been tilled since 1940 with a moldboard plow, disk or subsurface sweep (Pikul and Zuzel, 1994). In contrast, plots receiving the highest rate of nitrogen (160 pound N/acre/crop) applied to that experiment had 57 percent greater infiltration than plots receiving a rate of 40 pound N/acre/crop. Porosity of the surface crust was 12 percent greater for the high compared to the low rate of nitrogen application. On the crop residue experiment, which was cultivated with a moldboard plow, the porosity of the surface crust was 29 percent greater for soil receiving only animal manure, compared to soil that was not fertilized and also had the stubble burned during the autumn. Porosity of the surface during the winter increased for treatments receiving only manure or only inorganic fertilizer (80 pound N/acre/crop) and decreased for the treatment which was not fertilized and stubble was burned. Porosity of the surface crust was highly correlated with the concentration of soil organic carbon. Pikul and Zuzel (1994) concluded that it was imperative to use crop management practices that conserved or increased organic carbon to develop porous soils with high rates of infiltration.

About 10 years later, additional studies of infiltration characteristics of treatments in the long-term crop residue experiment were reported by Drs. Stewart Wuest and John Williams (Wuest et al. 2005). These authors compared infiltration rates with a broad range of soil properties in the top four inches of soil. Some of the measured factors included organic carbon, organic nitrogen, water stability of whole soil, aggregate stability, soil-aggregating fungi, and earthworms. Infiltration correlated highly with carbon, nitrogen, and soil stability, each of which were much higher where only manure or pea vine straw was added to the plots since 1931. These factors were lowest where no nitrogen fertilizer was applied and the stubble was burned during the autumn. Wuest et al. (2006; Appendix 4) also reported infiltration rates in the long-term rotation of winter wheat and spring pea, established in 1963. Infiltration was two-fold higher where soil was tilled with a subsurface sweep compared to a treatment cultivated with an offset disk after wheat harvest and with a chisel plow after pea harvest. Infiltration into the sweep treatment was four times greater than into plots that were moldboard plowed either during the autumn or the spring. Likewise, infiltration in the long-term tillage-fertility experiment, since 1940, was twice as high in the disk and sweep treatments as in the moldboard plow treatment. Wuest et al. (2006a) also measured infiltration rates in three tillage treatments of a 7-year old no-till annual winter wheat experiment. Infiltration was higher in soils that were not tilled than those that were tilled such that residue was either incorporated or left on the surface. In that experiment they also found that water-stable aggregation was two-fold higher in the no-till than in the cultivated treatments. Similar relationships were also reported for measurements made during two years for seven different soil series in Umatilla County (Wuest et al., 2006b). Infiltration rates were highest when fields were, for the longest periods of time, used to produce wheat without tillage, or were managed as a grassland, such as in the Conservation Reserve Program.

Dr. Wuest also conducted a pot and field study to examine whether leaving wheat stubble on the surface (no-till) or incorporating it into the soil influenced the size and strength of soil aggregates. He determined that the no-till treatment had aggregates of greater diameter in the surface two inches of soil (Wuest, 2007b).

Dr. Wuest compared rates of water infiltration with numbers of earthworms in the long-term rotation of winter wheat and spring pea (Wuest, 2001). Both infiltration and numbers of earthworms were greater in a minimum-tillage treatment (only shallow skew treading to incorporate weed seed and break the stubble) than in any of the treatments in which soil was disked, chiseled or turned over with a moldboard plow. However, these two measurement may not have been directly associated. The only earthworms that were present were of a species that do not create burrows at the soil surface. Also, the numbers of earthworms were very low, and they were almost absent in soils that were tilled. This is apparently typical for most of the cultivated soils in the low-rainfall regions of eastern Oregon. Nevertheless, earthworms and infiltration rates are each directly associated with soil properties such as improved soil aggregation and higher concentrations of soil organic matter.

Water Storage and Extraction by Crops

For water to become effective for plant use between periods of precipitation, the water that entered the soil must move downward into the soil profile, but must not move to depths below the plant root zone. Production of dryland winter wheat in wheat-fallow rotations is heavily dependent on water stored in the soil during the fallow winter, plus additional rainfall during the spring of the crop year.

Monitoring of soil moisture in soil profiles began soon after the crop rotation and tillage experiments were established at the Sherman Station in 1912. These investigations of moisture distribution at various depths became more formalized and were greatly intensified in 1919. Moisture samples were collected at intervals throughout the crop season to determine the amount of water extraction occurring at various soil depths during the crop year. This was a collaborative effort with the Soils Department of the Oregon Agricultural College. One year later, in 1920, the tests for soil moisture were again intensified and the analysis of nitrogen concentrations was added to the testing protocol. The study of water and nitrogen storage in dryland soils was therefore well-defined and began to include studies at Pendleton almost immediately after the Pendleton Station was established. An example of the huge magnitude of those studies was reported in the Sherman Station's 1932 Annual Report. Data were reported for soil moisture measurements taken to a depth of six feet in many of the experiments and rotations. Those measurements were made repeatedly through the crop year, and showed the rate of extraction of water and the downward movement of nitrate with the water during the growing season.

Most of the myriad of studies on tillage and residue management had as a driving force and therefore a critical component, the measurement of soil moisture. As stated in Chapter 13, detailed results and summaries of those studies were recorded in the Annual Report from each Station, until that series of reports was terminated in 1974. More recently, most reporting has been through papers published in professional journals. The intent of this portion of this chapter is to communicate the types of issues that were addressed and some of the most important findings from more recent studies. Key scientists who measured water storage and extraction from soil most recently include Drs. Stephen Machado, Bill Payne, Bob Ramig, Dale Wilkins, John Williams and Stewart Wuest.

Dr. Bob Ramig studied water storage efficiencies over a 6-year period in the long-term winter wheat-spring pea rotation at the Pendleton Station. He found that standing stubble stored an average of 87 percent of the winter precipitation (Ramig and Ekin, 1976 and 1978). In contrast, when stubble was plowed during the autumn, the storage efficiency was reduced to 64 percent. The extra amount of water (2.5 inches) stored in the top eight feet of soil below standing stubble was directly responsible for the 25 percent increase in average yields of green peas in the rotation. Moreover, the 0.7 inch of extra water that had not been extracted by the shallow-rooted peas became available to the wheat crop that followed peas in the rotation, resulting in an increase of wheat yield by two bushels per acre. The efficiency of water capture was only 32 percent when pea stubble was planted to winter wheat. Peas used 89 percent of their water from the top four feet of soil, and winter wheat used 95 percent

David Robertson and Dr. Don Wysocki using a soil probe to collect samples to determine soil water content of its water from the upper six feet of soil. When wheat stubble was plowed after harvest, evaporation caused a loss of 68 percent of the winter precipitation during the driest winter (Ramig and Ekin, 1978). In a wet winter, 90 percent of the precipitation was stored because evaporation was minimized during long periods of damp, cloudy weather. The range of water storage efficiency was much lower where the stubble remained standing during those winters; storage ranged from 80 percent to 96 percent, with an average of 87 percent. Dr. Stephen Machado followed upon these water studies in the long-term winter wheat-spring pea rotation, and extended the reporting period for that work to seven years (Machado et al., 2008). Results were essentially the same but were reported in greater detail and in a formal publication, and included additional calculations of water-use efficiency, as described later in this chapter.

Ramig and Ekin (1984) reported similar water storage investigations over four fallow-wheat cycles at locations near Pendleton, Moro and Ione. They found that stubble that was flail mowed after harvest stored as much water as fields in which stubble remained standing during the winter. No additional water was stored in any treatment during the hot, dry 8-month period from March 1 to October 31, and usually there was a net loss of moisture during that period.

Dr. Larry Lutcher, Field Crops Extension Agronomist in Morrow County, compared water storage at 10 sites where there were adjacent cultivated and no-till fallows about five miles north of Ione. All fields were managed as winter wheat-fallow rotations. Sampling to 5-foot depth in each field was conducted during mid-June and early September. Stored water in the tilled fallows was about 10 percent greater (0.55 inch) than in the chemical fallows during June, and 13 percent greater (0.67 inch) during September (Lutcher, 2003). Both treatments had slightly less water (0.2 - 0.3 inch) in September than in June. Those differences were not statistically different even though they may have been biologically important for wheat extraction during the following crop cycle. In both residue management systems, the distribution of water with depth was similar, albeit that the moisture contents at all depths were slightly higher in the tilled fallow than in the chemical fallow. Also, in both treatments, the maximum amount of soil water was found in the second foot below the soil surface. Water contents in the upper foot of soil were much higher in June (8-9 percent) than in September (5-6 percent). These findings are particularly relevant because water vapor is a primary source of water for seeds in unsaturated soils (Wuest, 2007a), as is discussed in Chapter 18. Dr. Dale Wilkins studied the retention of seed-zone moisture when using six different types of seed drill opener. Wilkins et al. (1983) stated that a soil moisture content of 9 percent or more around the seed would not delay seed germination and seedling emergence, and moisture contents of 6 percent or less would substantially retard seedling emergence. Drs. Stewart Wuest and Larry Lutcher also reported that the amount of water required to germinate wheat seed rapidly was about 6 to 9 percent, and that seeds germinated very slowly at water contents of 5 to 8 percent (Wuest and Lutcher, 2013).

Dr. Stephen Machado coordinated a long-term crop rotation and tillage management investigation at the Sherman Station, as described in Chapter 12. The experiment was established in 2003 and continues at this time, in 2020. Water storage and extraction were among the factors measured, but details of those relationships have not yet been reported. In a preliminary report, Smiley and Machado (2009) reported that the various treatments influenced populations of root-lesion nematodes in the soil, and these nematodes were found at depths as great as four feet. Winter wheat yield was inversely correlated with number of root-lesion nematodes. Annual winter wheat had the highest populations of nematodes, the lowest capacity to extract water from the soil profile, and the lowest grain yields, as compared to all other rotations. Compared to wheat in rotations, and with fewer nematodes, annual winter wheat was unable to extract as much as 50 percent of the water in the soil profile. That failure to use all of the water in the profile was attributed to damage caused by the nematodes, making it clear that even in very low rainfall areas, root diseases can greatly influence measurements of water extraction and water-use efficiency.

Larry Pritchett measuring soil water content using a PR2 probe

Dr. Stewart Wuest applied a novel approach to studies of soil water storage. He monitored soil water and temperature after preparing simulated tillage at two low-rainfall sites for two consecutive years. The simulated tillage was done on six dates (mid-May to mid-September) and four depths (0, 2, 4 and 6 inch). At each time, Wuest removed surface residue from a 3-foot diameter circle and used a shovel to remove soil to the appropriate depth. The soil was passed through a screen to break up clods, and the loose soil was then returned to the excavated hole. Soil water content was measured during late summer and early fall at 10 depth intervals in the top foot of the soil profile. Soil temperature was monitored at ½-inch depth intervals. Measurements were also made in areas of the surrounding fields to assure reliability of data from this experiment. It was determined that 'tillage' performed in mid-June at depths of four and six inches preserved more water than no tillage or tillage at 2-inch depth. The difference in moisture storage was sufficient to have a substantial influence on germination of winter wheat. The later or shallower tillage treatments produced water contents below the six-inch depth that were similar to fields managed without tillage. Wuest (2010) concluded that in order to optimize the timing and depth of summer fallow tillage, it would be required to 1) determine the amount of water stored during the spring, 2) predict the potential for additional water to be stored at the end of summer, and 3) calibrate that information for each soil type.

As mentioned earlier, additional recent studies have also been published by Drs. John Williams and Stewart Wuest. References to those reports are shown in Appendix 3.

Evaporation from Soil Surfaces

The Inland Pacific Northwest is an excellent environment for producing winter wheat. The Mediterranean climate results in mild to cold winters and hot dry summers, with 70 percent of precipitation falling from October to March, and most of the rest falling from April to June. The native vegetation was dominated by cool-season perennial bunch grasses and sagebrush that made rapid use of stored soil water as the weather quickly became warm before the hot, dry summer. Growth of native vegetation halts during early summer due to an almost complete lack of precipitation. Early settlers found that winter wheat was a highly productive crop which produced adequate yields even in years when spring rains were sparse. Spring crops, on the other hand, were not able to develop root systems capable of reaching water stored deep in the soil profile before hot, dry weather arrived.

A major challenge in growing winter wheat in the driest half of the region where precipitation is <14 inches annually is to establish the crop before the weather turns cold in November. Substantial fall precipitation after the summer drought often does not occur until mid- to late October, providing little time to seed a crop into surface moisture and have plants put down roots and become hardened before cold winter weather. A solution to that problem is to grow winter wheat in rotation with a year of fallow, meaning that the ground is without a crop for about 14 months following harvest in July or early August. This so-called 'summer fallow' period allows about 30 percent of the precipitation occurring during the fallow period to be stored in the soil to prepare for seeding winter wheat in September. Early farmers found that frequent, shallow tillage for weed control created a soil mulch which kept the soil moist below the 'dust mulch.'

In the late 1960s, special deep furrow drills were developed to seed into that 'deep moisture.' Thus, a crop could be established with reasonable reliability even in the absence of any fall rain. This system of tilled summer fallow with a relatively fine dust mulch is still the basic practice in much of the region. The major drawback is that the soil is very susceptible to wind and water erosion. No-till summer fallow has been successfully adopted in certain regions, such as the U.S. Great Plains where early fall rains are likely, and in areas of the Inland Pacific Northwest that receive more than 15 inches of annual precipitation. No-till provides excellent water infiltration and erosion control. Without a mulch of tilled soil on the surface, however, summertime soil drying is often too deep to allow early seeding into adequate water, even using deep-furrow drills. At some locations, such as throughout east-central Washington, a failure to establish the crop early causes substantial yield reductions and additional cost when fields need to be replanted nearer the time when rains are predicted.

The phenomenon of maintaining moisture at the depth where seed will be planted by pulverizing the overlying soil was first observed by farmers but received substantial refinement and quantification through research at the Sherman and Pendleton Stations, as well as at other dryland research sites. At the Sherman Station, rates of evaporative water loss in 1922 were compared on untouched soil, soil mulched (pulverized) to a depth of one inch, and soil for which the loose soil had been scraped off to provide a smooth hard surface. All weeds were pulled by hand. The moisture contents of the three plots were the same. During the fallow season, the untouched and scraped plots lost twice as much moisture as the mulched plot. That field experiment was repeated with soil placed into large cans, which would today be called galvanized garbage bins. Mulching the soil surface clearly helped conserve moisture. Thereafter, extensive measurements were made to compare differences in moisture and nitrate among soils in various tillage treatments, between 'good' and 'poor' fallow, and between cropped or uncropped plots. Many pages in the Sherman and

Pendleton Station Annual Reports presented data and interpretations of soil water data. Much attention was also devoted to quantifying the water requirement of different crops. No attempt was made to encapsulate those findings into this summary of research by station scientists.

It was clear that farmers needed tillage methods that preserve seed-zone water as well as resisted erosion by wind and water. Research at the dryland stations in Oregon focused on investigations on timing, depth and intensity of tillage. It was shown that highly tilled soil mulches were not necessary for effective reduction of evaporation. Scientists began examining ways to develop coarse mulches that were effective on major soils found in the region. They also studied the timing of spring tillage for minimizing evaporative loss without reducing infiltration of spring precipitation. Adoption of these reduced tillage methods greatly reduced soil erosion by wind and water, while also reducing fuel and labor costs, and often also reducing soil crusting and the need to replanting fields in which the wheat stand failed to become established when first planted.

More recent research has quantified evaporative losses of water from soil surfaces in large numbers of experiments. As an example, Ramig and Ekin (1978) reported data from the long-term winter wheat-spring pea rotation at the Pendleton Station. They determined that 15 percent of the precipitation was lost through evaporation when rainfall occurred during August and September. Results varied over the winter, depending upon tillage practices. When wheat stubble was plowed after harvest, 68 percent of the winter precipitation was lost through evaporation during the driest winter, compared with only 10 percent during the wettest winter. In the wet winter, 90 percent of the precipitation was stored because evaporation was minimized during long periods of damp, cloudy weather.

In similar research at the Sherman Station, Russelle and Bolton (1978) reported that residual moisture was maintained near the soil surface through the summer of the fallow period by the dust or stubble mulch. The rate of moisture loss accelerated in late August and September, which dried the normal planting zone and forced either planting deeply to reach adequate seed zone moisture or delaying seeding until adequate rains fall. Both deep and delayed planting could result in stands which became established later, were less vigorous, and were less helpful in controlling soil erosion. Deep plantings that are rained upon before seedling emergence may also form a surface crust that reduces emergence and stand density. In the worst instances, crusting causes a total failure of the planting, requiring an expensive repeat planting, which often results in a lower grain yield due to the delayed planting date. Bolton (1981) reported that, throughout the region, productivity of winter wheat is much higher when it is planted between September 15 and October 15, as compared to earlier or later plantings.

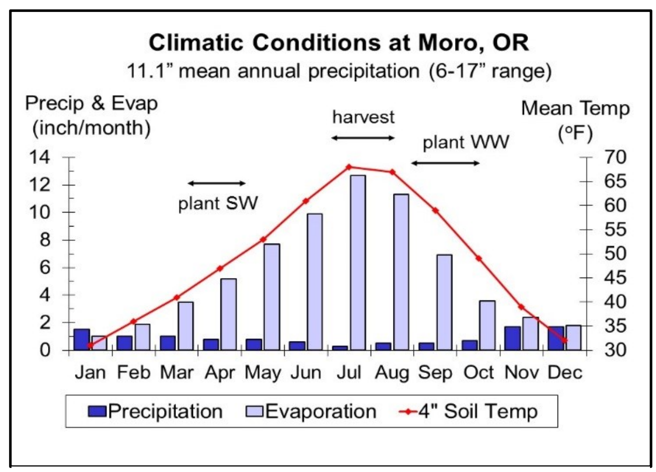


Illustration of the high evaporative potential relative to low amounts of precipitation at the Sherman Station

Drs. Joe Pikul and Raymond Allmaras studied associations between the flow of heat and the rate of evaporation from the soil surface during the summer. Using a mathematical model, they found a close correlation between heat conduction and moisture content of the seed-zone during a dry summer at the Pendleton Station (Pikul and Allmaras, 1984). The model was less accurate during a wetter year. Drs. Pikul and Allmaras also studied the influence of temperature change during late summer on the rate of water evaporation through the surface dust mulch at the Tad Miller farm 20 miles north of Heppner. They precisely measured temperatures and evaporation rates during a dry and a wet year and were unable to directly associate cooling daytime temperatures during the autumn with increasing rates of evaporation (Pikul et al., 1985). As expected, the net transfer of heat energy shifted from a downward direction during the summer to an upward direction during the autumn. The evaporation rates remained high even as soil temperatures became cooler during the autumn. It was noteworthy that Pikul et al. (1985) demonstrated that the water-conserving benefit of the mulch layer disappeared whenever rainfall consolidated the mulch layer.

Drs. Dale Wilkins and Steve Albrecht stated that an important reason that chemical fallow had not replaced cultivated fallow in the lowest rainfall regions was the lack of adequate soil moisture in the seed-zone at the time that winter wheat is planted. They therefore compared soil moisture at seed-zone depth in chemical and cultivated fallows at the Pendleton Station (Wilkins et al., 2003). The plots had variable rates of nitrogen applied, which resulted in different amounts of straw production. The cultivated fallow had about 5,000 pounds of surface residue per acre. They determined that the moisture content of the surface four inches of chemical fallow increased in proportion to the amount of surface residue remaining from the previous harvest. When the amount of surface residue was 7,200 pounds per acre, or more, wheat stands became established rapidly and, in November, the numbers of seedlings were equivalent in chemical and cultivated fallows. However, by January, the number of seedlings in all nitrogen and tillage treatments had become equal, including those low-fertility, low-residue treatments in which the stand establishment had been delayed.

Drs. Stewart Wuest and Bill Schillinger also stated that the erosion-suppressing properties of chemical fallow was an ultimate goal for farmers in areas that receive 12 or fewer inches of precipitation. But most farmers in those regions continue to cultivate fallow to create a surface mulch to reduce evaporation so they can begin planting winter wheat as early as late-August, which is critical for achieving maximum agronomic yield potential in those dry regions. In view of previous findings by Wilkins et al. (2003), and others, it became important to determine if chemical fallow would eventually accumulate enough surface residue to retain seed-zone moisture equivalent to that of cultivated fallow. Wuest and Schillinger (2011) conducted a 6-year study at the Washington State University Dryland Research Station, at Lind, where the mean annual precipitation is 9.5 inches. They compared soil water dynamics in a 2-year winter wheat-cultivated fallow rotation and a 3-year winter wheat-spring wheat-non-tilled fallow rotation. The cultivated fallow was prepared with sweep tillage (a V-blade undercutter with simultaneous application of fertilizer) followed by rod weeding once or twice during the summer. The stubble remaining after harvest in the chemical fallow treatment was about 1,700 pounds/acre. Additional stubble for an adjacent field was distributed over sub-plots of each chemical fallow treatments to elevate residue levels to totals of 6,700 and 11,800 pounds/acre. The highest residue cover was about twice the amount that could be expected to be produced during the most productive, highest rainfall, years at that location. They measured soil water at various depth increments on three occasions during each of the six fallow periods. In that region, deep-furrow drills can be used to place wheat seed as deep as 10-inches into the soil to reach soil moisture contents sufficient to rapidly germinate wheat seed. By supplementing the amount of residue on the soil surface, the seed-zone soil moisture was incrementally increase at the time of planting, but even with 11,800 pounds/acre the seed-zone was drier under chemical fallow than where the fallow was cultivated and surface mulched with the rod weeder. The efficiency of water storage varied from 33 percent for the lowest residue load on chemical fallow to 40 percent for cultivated fallow. Wuest and Schillinger (2011) concluded that 1) water loss during the summer is greater for chemical fallow than cultivated fallow, 2) drying of the seed-zone is more extensive and occurs more deeply for chemical than cultivated fallow, 3) increasing amounts of surface residue slow the rate of evaporative loss from late-summer rains, and 4) chemical fallow at all levels of surface residue is unlikely to retain enough moisture near the surface to allow early-planted winter wheat to successfully emerge from deep plantings. The challenge for retaining sufficient moisture to attain maximum productivity while also minimizing the potential for erosion of soil by wind or water has not yet been overcome in the driest production regions.

Efficiency of Water Use by Crops

Many factors affect the ability of plants to extract water stored in the soil profile. Because water is a major factor that limits the productivity of crops in semi-arid regions, the efficiency of water use becomes critical. Water-use efficiency is defined as the unit of economic yield produced per unit of precipitation received during the entire period for that crop, including the fallow period.

The first soil water experiment at the Sherman Station was established during 1911, in cooperation with the USDA Biophysical Laboratory and the Office of Alkali and Drought Resistant Plant Investigations of the USDA-BPI. Large pots (16-inch diameter × 26-inch high) were used to determine the water requirements of wheat and alfalfa. The pots were filled with surface soil tamped to a density similar to that in the field. The tops were covered so that the only water removed from the pots was that which came through the plants via transpiration. Seed was planted through 0.5-inch-diameter holes for each wheat seed, and 1-inch-diameter holes for each alfalfa seed. Six replicate pots were planted for each of the two crops. After planting on May 5, the pots were weighed and water was applied as many as 25 times. Crops were harvested to determine ratios of water to dry matter and grain produced.

Similar studies were established in 1919 and again in 1923. Soils were collected at Pendleton and Moro. The goal was to determine water-use-requirements of multiple wheat varieties in each soil. The study initiated in 1919 consisted of large, open pots that contained variable amounts of surface straw to determine the water-use requirements for winter wheat in various tillage treatments. Some treatments were discontinued after eight years because the scientists had already determined that water-use requirements differed somewhat among the various tillage systems. The remaining treatments were continued for 24 years. For the 1923 experiment, cans with covered tops were compared to cans that had no covering over the soil surface. Results were compared with the water-use-requirements of the same varieties grown under field conditions. By 1942, each of those studies revealed that winter wheat produced an average of 2.6 bushels for each inch of moisture used, and that annual variation in water-use efficiency was from 1.5 to 4.1 bushels per inch (Stephens et al., 1943).

Extensive amounts of data on soil water were reported in the 1942 Sherman Station Annual Report for selected treatments in the tillage and rotation field experiments. One novel experiment during that era determined the water requirements of clipped or unclipped Russian thistle.

Water-use efficiency values have risen over the years, due mainly to overcoming production hazards that prevented wheat from yielding to the upper limit of its potential water-use efficiency. In Washington, during the 1950s, it was determined that 4.0 inches of water were required to satisfy the requirement for vegetative growth of wheat plants, and that 5.6 bushels of wheat per acre could be expected from each additional inch of water available to the crop, including water stored in fallow, plus rainfall during the spring of the crop year (Leggett, 1959). Cook and Veseth (1991) stated that the genetic potential of wheat was about 7 bushels/acre for each inch of water after the 4-inch requirement for vegetative growth had been met. They also stated that the lower values actually realized were due to environmental and disease factors that restrict wheat yield. Recent studies indicate that modern wheat varieties require about 2.3 inches of water to satisfy vegetative growth, and then produce 5.8 bushels per acre for each additional inch (Schillinger et al., 2008).

Many studies of water-use efficiency do not differentiate water required for vegetative and reproductive growth. Efficiency is reported based upon wheat produced for the total amount of stored water and in-crop precipitation available to the crop. During the 1980s, Dr. Bob Ramig summarized five years of research at the Sherman Station. The efficiencies under various tillage treatments ranged from 4.6 to 5.3 bushels/acre/inch of water (Ramig, 1988). Efficiencies were higher than 5.0 when stubble was burned or disked during the fall, or plowed during spring. Lower efficiencies were realized when stubble was flailed or chiseled during the fall, or swept with a sweep during the spring.

Dr. Ramig also conducted extensive water-use-efficiency investigations throughout eastern Oregon. In cooperation with Dr. Charles Rohde, Ramig established large experiments on three farms; Ronald Rew (12 miles WNW or Pendleton), John Weidert (15 miles WNW of Helix), and Sam Crow (1.5 miles SW of Weston). Tests were repeated over four years, including wheat crops harvested from 1962 until 1965. The experiments included replicated combinations of three winter wheat varieties, five planting dates, and nitrogen application rates of 0, 40, 80, 120 and 160 pounds N/acre. Measurements were made of soil water content to six-feet depth and of crop yields, grain test weights and protein contents. Similar studies over shorter durations were conducted in Union, Baker and Malheur counties. Ramig also conducted water infiltration studies to compare 'deep' and 'normal' plowing depths under sprinkler irrigation systems at the John Story Farm. Those tests were from 1962 until 1969. He measured water infiltration rates, water in the soil profile, crop yield, grain test weight, and protein content.

Dr. Ramig also conducted studies from 1978 until 1990 on the efficiency of summer fallow for preserving water in the soil profile during each season of the year. These studies were again performed on farms throughout the region, some of which included the farms of Joe Reitman (Morrow County), Eric Anderson (Morrow County), Charles Doherty (Morrow County), Tom Martin (Sherman County), Steve Burnett (Sherman County), and Calvin Spratling (Umatilla County). Ramig and the cooperating farmers measured precipitation, water storage in the soil profile, wheat yield, grain test weight, and protein content. Ramig used the data to calculate water-use efficiency for wheat production in those regions, and he provided guidelines as to times during dry years when farmers might find value by using a double-fallow sequence between crops rather than a single fallow (Ramig, 1988; see Appendix 4).

Dr. Stephen Machado determined water storage, water extraction and water-use efficiency for both phases of the long-term winter wheat-spring pea rotation at the Pendleton Station. Water-use efficiency was highly correlated with yield of winter wheat in all four tillage treatments (Machado et al., 2008). The water-use efficiency ranged from 3 to 7 bushels/acre/inch of water, and was highest when yield was highest, and lowest when grain yield was lowest. The correlation between efficiency and yield was highest in the minimum-tillage treatment, where the wheat stubble and soil surface was shallowly skew treaded after wheat harvest and a subsurface sweep was used shortly after pea harvest. However, the water-use efficiency was higher in the intensively plowed treatments than in the minimum-till treatment. Tillage had no significant effect on water-use efficiency during years in which peas were produced but, again, the correlation between efficiency and yield was highest during years when yield was highest. Overall, the peas had greater water-use efficiency than winter wheat but the trend lines were almost parallel.

Many other studies of water storage and water-use efficiency have been conducted throughout the region. Recent studies have been reported by Drs. John Williams and Stewart Wuest (see Appendix 3). One such study at the Pendleton Station compared, over an 8-year period, the water relationships in a winter wheat-fallow rotation (chemical fallow versus sweep-tillage fallow) and in annual no-till winter wheat (Williams et al., 2015). Precipitation storage efficiencies did not differ among treatments but, in the wheat-fallow rotation, more water appeared to be stored in the chemical fallow than in the sweep-tillage fallow; 6.4 versus 6.0 inches of water. Annualized grain yields were greater for annual wheat (76.7 bushels/acre) than the fallow rotations (43-49 bushels/acre), leading to a 30 percent greater efficiency for converting precipitation into grain yield in the annual crop (4.0 bushels/acre/inch of water) than in the rotations (2.2 - 2.5 bushels/acre/inch of water). The authors concluded that a way to maximize water-use efficiency in lower rainfall zones may be to produce winter wheat without tillage, either annually or in a wheat-fallow rotation. The authors also cautioned that comparisons of chemical fallow and sweep-tillage fallow at sites with substantially less rainfall than at the Pendleton Station have produced water storage relationships opposite those reported for the Pendleton Station.

Managing Frozen Soils

Much of the soil erosion in the Pacific Northwest occurs on frozen soil. In contrast, heavy rain events are the dominant cause of soil erosion in other regions. Soil losses in the Pacific Northwest can be especially high when heavy rainfall or rapid snow melt occurs at a time when subsurface soil layers are frozen. A frozen soil layer, much like a severely compacted soil layer, greatly reduces internal water movement. Poor internal drainage impairs water movement into the soil, thereby increasing water runoff and erosion of soil that thaws at the surface. Serious erosion can occur on soils that are frozen only three inches deep.

Snowmelt water perched on layer of frozen soil (at 1-inch depth) at the Pendleton Station, in 1984

Gully erosion from frozen soil near Athena

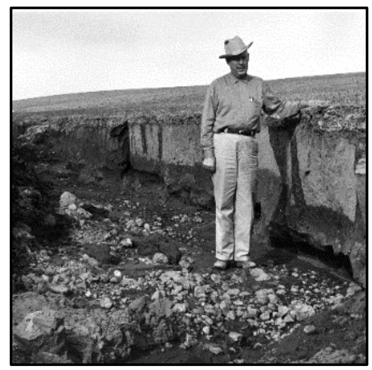
Drs. John Zuzel and Joe Pikul studied 30 years of historical records for soil freezing at the Sherman Station. They developed a mathematical model that accurately simulated and predicted those events (Zuzel et al., 1985). They determined that frozen soil events occurred at least once every year at the Sherman Station, and there were at least three freeze-thaw cycles during about half the years, and as many as seven freeze-thaw cycles during five percent of the years. The number of days in which the soil was frozen ranged from 6 to 116 days, with a mean of 57 days per year. Zuzel et al. (1985) also determined that frozen soil events occurred during two-thirds of the days in January, half the days in December and February, and less than 10 percent of the days in November and March. This analysis was important because freeze-thaw cycles are a major factor in reducing the stability of aggregates near the soil surface, and in increasing the capacity of the soil to erode.

However, the freezing of sol is a complex issue. There are various types of soil frost, and each type has a different effect on infiltration and erosion. The types of soil frost are described as granular, honeycomb, stalactite and concrete. Granular frost has a porous structure that does not seriously impede water infiltration. It occurs mostly in woodland soils. Concrete frost greatly impedes water infiltration and this is the form found mostly in bare agricultural soils.

However, the moisture content of the soil at the time of freezing greatly affects the permeability of the frozen layer. Frozen soils with low moisture content may become granulated. Wet soils often freeze into a massive, concrete state that is nearly impermeable to water movement. Poor internal drainage, such as caused by a tillage pan, may perch water near the surface, predisposing the soil to the formation of concrete frost during freezing weather. Night-time loss of radiant energy often causes the surface soil to freeze. Water is drawn to the surface from a shallow soil depth, and freezes at the soil surface. That frozen surface may then thaw and become drier when ambient temperature increase during the day, or when radiant energy from the sun heats the surface layer. Frequent freezing and thawing of silt loam may seriously degrade soil structure. This repetitive wetting and drying of the soil surface accelerates the disintegration of soil aggregates, which increases surface crusting and decreases infiltration.

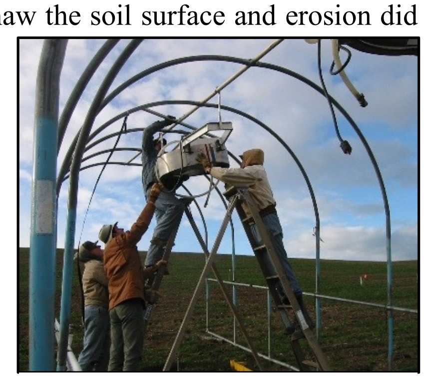
Rill erosion near Dufur

Tillage and residue management have significant effects on frost formation, frost structure, and water infiltration. Deep tillage creates fractures and large pore spaces in soil, which allow water infiltration under conditions of relatively shallow freezing. Surface residues reduce the frequency and depth of soil frost, and decrease the severity of freeze and thaw events (Pikul, 1982; Pikul and Allmaras, 1985; and Greenwalt et al., 1983).



Merrill Oveson in a gully cut through frozen soil near the Pendleton Station - 1965

Pikul et al. (1985) measured water infiltration on a Walla Walla silt loam at the McCormmach Ranch near the Pendleton Station. The field was a winter wheat-summer fallow rotation in which primary tillage was with a moldboard plow. There was a tillage pan at a depth of about eight inches, caused by the moldboard plow. The scientists borrowed a 'Palouse Rainfall Simulator' from the Soil Conservation Service to evaluate infiltration in fall-planted winter wheat, standing stubble, and standing stubble that had been chiseled to a depth of ten inches. When water infiltration tests were conducted in early January, the soil was frozen to a depth of six inches in the in-crop treatment, five inches in the chiseled treatment, and four inches in the standing stubble treatment. Moreover, the demarcation line between frozen and unfrozen soil was at a uniform depth for the in-crop and standing stubble treatments, and was of very irregular depth in the chiseled treatment. In these tests, the simulated rainfall did thaw the soil surface and erosion did not occur even though excess water ran off the plots. Infiltration of water was much greater in the chiseled treatment than in the standing stubble or in-crop treatments; 3.4, 1.2, and 0 inches per day. In contrast, during the autumn, on unfrozen soil, the respective infiltration rates were 8, 5 and 2 inches per day. By early February, the soil became frozen to a depth of 14 inches in the in-crop and the chiseled stubble, but frost penetrated only half as deep where there was standing stubble.



Constructing a simulated rainfall structure over a field of winter wheat

Dr. Dale Wilkins and Roger Goller taking notes on runoff during a 'rainfall' event

Pikul et al. (1992) subsequently determined that chiseling improved water infiltration only when the depth of frost was less than the depth of tillage. Chiseling did not improve infiltration when the depth of frost exceeded the depth of tillage. Chiseling also did not improve water infiltration in unfrozen soil, unless the depth of chiseling reached well below the tillage pan, into the zone where soil bulk density was unaffected by tillage operations.

From 1959 until 1961, scientists at Pendleton examined a process for reducing water runoff and soil erosion, especially on frozen soils. Experiments were conducted at 20 sites in northeast Oregon (from Moro to Milton-Freewater), eastern Washington (from Walla Walla to Spokane), and northern (Bonner's Ferry to Moscow) and eastern (Pocatello to Rexburg) Idaho. The lead scientists were Charles Smith, Theodore Horning, Merrill Oveson and, upon his arrival during the final year, Dr. Robert Ramig. Their research involved a process called vertical mulching. A special machine was used to rip vertical channels in soil and then fill the channels with straw. The machine was borrowed from a company in Illinois. It had a heavy-duty subsoil shank with tapered wings, and a forage chopper that mangled the straw and blew it into the trench. The intent was to maintain avenues for water penetration even while soil was frozen. The experiments evaluated erosion at the test sites and also cultural methods that could be used to extend the useful life span of the channels.

Vertical mulching equipment and views of the field surface and a straw-filled trench

The complexity of vertical mulching treatments and the types of measurements taken from these experiments are revealed by major conclusions from that research. There were no differences in wheat yields among treatments without trenching, or with trenches that were filled or empty (no straw). In low rainfall areas, such as in Sherman and parts of Umatilla counties, wheat plants failed to establish in bands 12 to 20 inches wide over the trenches. There were no tillage difficulties encountered if the tillage was at an angle to the trenches, and there were no seeding difficulties using four makes of deep-furrow drills. Soil moisture losses during the summer fallow were the same from trenches left open at the top (chemical fallow) and trenches covered over by normal mechanical tillage methods. When trenches were installed during the spring prior to summer fallow, soil moisture difference were not greatly affected by the presence or absence of trenches. When trenches were installed in the dry soil during the fall, in stubble, soil moisture content the following spring was greater in the trenched than in the non-trenched plots. There was no erosion across the trenched areas except when the soil was frozen.

Wilkins et al. (1991) evaluated the possibility to maintain infiltration and erosion reduced by creating infiltration channels when fields were in-crop and the soil surfaces were frozen. They developed a rotary subsoiling tool that caused minimum soil disturbance while poking holes through soils that were frozen to depths up to six inches. The rotary subsoiler consisted of a deep chisel pulled in front of a spider wheel with five 'spuds' that penetrated to depths upto 14 inches at about 3-foot intervals. The chisel produced a slot that intercepted runoff from rain or melting snow, temporarily stored water, and provided an infiltration pathway through the frozen layer. Wilkins and Zuzel (1994) compared the use of various configurations of this implement over a 3-year period at six sites in northeast Oregon. They used treatments of the chisel shank only, the chisel and the spider wheel, the spider wheel only, and no tillage. All treatments were applied after the soil had frozen to a depth of about four inches, and the tillage depth was to 11-inch depth following the slope contour. Slopes varied from 15 to 25 percent, and tillage lines were at 20-foot intervals down the slopes. Winter wheat was in the seedling stage at the time the treatments were applied. The chisel shank alone made a narrow slot that remained open during the winter. The spider wheel left pock marks that served as

Chiseling on the contour through frozen soil in a field of dormant winter wheat small reservoirs for water in the shank pathway. The spider wheel alone sometimes was unable to penetrate frozen soil if a channel had not been created with the chisel shank. Infiltration was measured for two treatments, the chisel plus spider (rotary subsoiler) and the non-tilled treatment. Infiltration was greatly increased where frozen soil had been broken by the rotary subsoiler. Wheat yields were not affected by tilling frozen soil while wheat seedlings were still small.

Similar research was repeated more recently in eastern Washington (Williams et al., 2006). One experiment was conducted during each of six years. Experiments during the first four years were at different sites, and the last three years were at a single site. The rotary subsoiler was a heavier commercial model and did not have a chisel to create a channel in front of the spider wheel. Also, the implement was used after winter wheat had emerged and sufficient rainfall had occurred to prevent collapse of the pits created by the spider wheel. Water infiltration and water runoff were measured in plots that were untreated or were rotary subsoiled. The subsoil treatment improved storage of water in the soil profile during only two of the six years, indicating that the untilled soil lost more water to runoff during those years. During a year when the soil was frozen to a depth of two inches, the use of a 'Pacific Northwest Rainfall Simulator,' described by Williams et al. (1998), revealed that runoff was twice as great from the untilled than the subsoiled treatment. The mass of soil eroded from the untilled treatment was also twice that from the subsoiled treatment. As with previous research by Dr. Dale Wilkins, wheat yields were not improved, suggesting that there might not be an economic benefit from this erosion-control practice.

A rotary subsoiler

Managing Localized Indurated Clay Pans

Scientists at the Pendleton Station have, since 1931, observed small circular or irregularly-shaped areas in which the wheat becomes stunted during drier years (see Chapter 6). During wetter years, the patches generally do not occur unless the field or an experimental treatment within the field has been heavily fertilized. Dr. Foster Martin, a wheat breeder at the Pendleton Station stated in 1931 that "*The 'hard pan spots' ruined the replication of the winter wheat nurseries on the station. It was a drier-than-normal late spring and a hot, dry summer, causing varieties to ripen prematurely*." Martin also stated that his cereal testing nursery near Pilot Rock was "*riddled with hard pan spots*." Other early scientists reported that these spots were also very common in some fields at the Pendleton Station.

The localized dry spots are common throughout the eastern Columbia Plateau and can cover as much as 40 percent of the land area in some fields. Measurements of wheat yields inside and outside the patches during 1959 revealed that grain yield was depressed by as much as 30 bushels/acre inside the patches. Soil excavations at that time revealed that the patches contained a hardpan that prevented root penetration below depths that varied from 21 to 30 inches. Outside the patches, wheat roots penetrated to depths of four to five feet into the Walla Walla silt loam.

Extensive research to describe the patches and their effect on grain yield was conducted during the 1960s (Pendleton Station Annual Reports for 1960, 1961, 1963, 1964 and 1969). That research was led by Charles Smith, Ted Horning, and Dr. Bob Ramig (all of USDA), and Merrill Oveson (joint USDA and OAES). They collaborated with soil scientists from the USDA-SCS to provide detailed descriptions of two soil profiles on the Pendleton Station – one with and the other without a hardpan. Those profile descriptions are on pages 87-93 of the Station's 1960 Annual Report. These localized patches have for several recent decades been called 'leopard spots' or, more accurately, 'indurated clay pans.'

The patches were described again in the Station's 1961 Annual Report, at which time a deep-plowing experiment was initiated in an attempt to disrupt the clay pans and improve water and root penetration through the obstructed zones. The small, localized claypan spots were described as follows. "*On the Pendleton Branch Experiment Station and adjoining farms, small, irregular, indeterminate areas appear in growing crops, caused by indurated claypan layers of impervious silt loam soil averaging 6 to12 inches thick and occurring at approximately 15 to 20 inches below the soil surface. These claypan areas are discernable in maturing grain or on fall plowed land in late winter when the surface soil becomes saturated with water above these spots while being more completely drained in surrounding areas. These noncontiguous claypan areas underlie up to 40% of the total land area in places causing measured yield reductions as high as 30 bushels per acre*."

"*Much of the land on the Pendleton Station has these claypan spots which preclude use of these areas for small plot experiments due to extreme soil variability and inaccurate results.*"

"*In green peas for freezing or canning, these spots cause dwarfing of vines, thinner stands, and reduced yields. These spots show moisture stress well ahead of the rest of the field area in the advent of hot weather or torrid winds. Such conditions often result in high tenderometer readings on the shelled peas, low yield or scalding, or may cause canneries to by-pass the field entirely*."

"*Winter wheat on hardpan areas may show signs of moisture stress at about heading time. Under low rainfall conditions and high rate fertilizer applications, the wheat becomes stunted in height and the kernels shrivel, giving measured yield reductions up to 30 bushels per acre*."

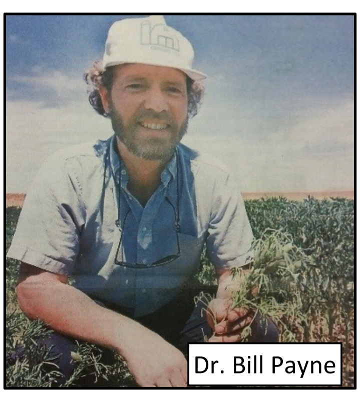
The researchers conducted an 8-year experiment at three locations; two on the Pendleton Station and one on the John Storie Farm between Mission and Pilot Rock. They compared deep plowing at a 3-foot depth, normal moldboard plowing to 8-inch depth, and stubble-mulch tillage in two fields managed as a winter wheat-fallow rotation and one field (at the Station) managed as a rotation of winter wheat and spring canning pea. The deep plow was rented from a farm in Mt. Vernon, Washington and was pulled by a borrowed D-8 Caterpillar. The plowing treatments were not repeated after 1961, but soil samples continued to be evaluated for differences in physical and chemical properties, weed species and weed populations, wheat yields, test weight and grain protein content.

Wheat yields were slightly greater on the deep-plowed treatment at all three locations during 1963. In comparisons of adjacent pan versus no-pan spots, the wheat yield was reduced from 45 to 90 percent when it was grown on the claypan spots. Green pea yields were slightly higher when the normal tillage was performed, but green peas had better tenderometer readings on the deep-plowed treatment and therefore the higher quality of pea brought in more income on the deep-plow treatment even though the pea yield was lower. The difference in plowing depth during 1961 in the wheat-fallow rotations had no effect on wheat yield, test weight, or protein during 1964. Wheat yields were slightly lower on the deep-plow treatment in the wheat-pea rotation. Peas were not harvested because a hard freeze at the end of May killed all the pea blossoms. At each of the three locations during 1968, a year with very low rainfall (11.0 inches at the Station), there was no difference in production or quality of wheat after fallow, wheat after peas, or peas after wheat as a result of the plowing treatments applied in 1961. Treatment effects were absent again at both wheat-fallow experiments during 1969, which was a crop year with more normal rainfall (15.7 inches) at the Station. However, wheat grown after peas during 1969 yielded 4 bushels/acre more where the soil had been deep plowed rather than plowed conventionally in 1961. The experiment was terminated in 1969.

These patches of indurated clay pans have continued to impose obvious irregularities in experiments on some fields at the Pendleton Station. Although the effects are similar, in that infiltration is restricted at some depth in soil, these indurated clay pans differ from restrictive layers caused by tillage, traffic, or migration of silica, which occurs especially in acidic soils (see Chapter 15).

Reliability of Soil Sampling Methods

OSU scientists, Drs. Bill Payne and Chengci Chen compared procedures for determining unsaturated hydraulic conductivity of the Walla Walla silt loam at Pendleton. They used elaborate instrumentation to measure water flow characteristics, and combined their data with earlier measurements on the same soil, as reported by USDA scientists Drs. Raymond Allmaras and Ron Rickman (Allmaras et al., 1977; Chen and Payne, 2001). Chen and Payne then applied the combined data to compare results when that data was applied to six different mathematical models that were designed by others to predict unsaturated hydraulic flow. They found that different models resulted in greatly different descriptions of hydraulic conductivity in the soil at Pendleton, and that the models didn't accurate correlate with the water characteristics that were actually measured. Chen and Payne concluded that it was not possible to reconcile the difference between models or between models and actual measurements.


Dr. Bill Payne

USDA scientist, Dr. Stewart Wuest, evaluated various methods used to estimate the rate of infiltration of water into soil. He determined that both size and shape of the infiltration device affected the results obtained (Wuest, 2005). By introducing a pulse of blue dye shortly before removing the infiltrometer equipment, Wuest was also able to visualize networks of flow pathways that were not associated with visible macropores in soil. He concluded that care must be used in selecting equipment to estimate saturated conductivity and possibly also unsaturated flow of water in soil.

Dr. Wuest also re-evaluated methods for measuring and reporting the bulk density of soil. Soil samples are typically collected with a tube inserted into soil to a pre-determined depth. Wuest (2009) established that compaction of soil when inserting the sampling tube creates a bias for measurements of bulk density. This becomes important when comparing tillage systems for water, carbon or other soil constituents. He concluded that it was very important to measure dry soil mass per unit area rather than by measuring the distance from the soil surface. This revised sampling protocol was especially important for comparing tillage systems, for reporting changes over time, and for minimizing differences due to the use of different persons or different types of sampling instruments.

***References*:**

Annual Reports from the Sherman and Pendleton Stations (Appendices 5 and 6)

Letters sent to or from the Station Superintendents

Allmaras, R. R., R. W. Rickman, L. G. Ekin, and B. A. Kimball. 1977. Chiseling influences on soil hydraulic properties. Soil Science Society of America Journal 41:796-803.

Allmaras, R. R., K. Ward, C. L. Douglas, Jr., and L. G. Ekin. 1982. Long-term cultivation effects on hydraulic properties of a Walla Walla silt loam. Soil and Tillage Research 2:265-279.

Bolton, F. E. 1981. Optimizing the use of water and nitrogen through soil and crop management. Plant and Soil 58:231-247.

Chen, C., and W. A Payne. 2001. Measured and modeled unsaturated hydraulic conductivity of a Walla Walla silt loam. Soil Science Society of America Journal 65:1385-1391.

Cook, R. J., and R. J. Veseth. 1991. Wheat Health Management. APS Press, St. Paul, MN. 152 pages.

Greenwalt, R. N., J. L. Pikul, Jr., and J. F. Zuzel. 1983. Soil frost penetration under conventional and conservation tillage. Oregon Agricultural Experiment Station Special Report 680:20-22.

Leggett, G. E. 1959. Relationships between Wheat Yield, Available Moisture, and Available Nitrogen in Eastern Washington Dry Land Areas. Washington State College Agricultural Experiment Station Bulletin 609. 16 pages.

Lutcher, L. K. 2003. Chemical fallow water storage in a low precipitation zone of north-central Oregon. Oregon Agricultural Experiment Station Special Report 1047:58-63.

Machado, S., S. E. Petrie, K. E. Rhinhart, and R. E. Ramig. 2008. Tillage effects on water use and grain yield of winter wheat and green pea in rotation. Agronomy Journal 100:154-162.

Pikul, J. L., Jr. 1982. Formation of soil frost as influenced by crop residue management. Oregon Agricultural Experiment Station Special Report 661:31-36.

Pikul, J. L., Jr., and R. R. Allmaras. 1984. A field comparison of null-aligned and mechanistic soil heat flux. Soil Science Society of America Journal 48:1207-1214.

Pikul, J. L., Jr., and R. R. Allmaras. 1985. Hydraulic potential in unfrozen soil in response to diurnal freezing and thawing of the soil surface. Transactions of the American Society of Agricultural Engineers 28:164-168.

Pikul, J. L., Jr., R. R. Allmaras, and C. R. Rohde. 1983. Water movement through tillage pans after 52 years of crop residue management. Oregon Agricultural Experiment Station Special Report 680:8-13.

Pikul, J. L., Jr., J.F. Zuzel, and R.N. Greenwalt. 1985. Water infiltration in frozen soil. Oregon Agricultural Experiment Station Special Report 738:6-11.

Pikul, J. L., Jr., J. F. Zuzel, and R. E. Ramig. 1990. Effect of tillage-induced soil macroporosity on water infiltration. Soil and Tillage Research 17:153-165.

Pikul, J. L., Jr., J. F. Zuzel, and D. E. Wilkins. 1992. Infiltration into frozen soil as affected by ripping. Transactions of the American Society of Agricultural Engineers 35:83-90.

Pikul, J. L., Jr., and J. F. Zuzel. 1994. Soil crusting and water infiltration affected by long-term tillage and residue management. Soil Science Society of America Journal 58:1524-1530.

Ramig, R. E. 1988. Water conservation and use in the semiarid Pacific Northwest. Pages 512-513. In: Challenges in Dryland Agriculture - A Global Perspective (P. W. Unger, T. V. Sneed, W. R. Jordan, and R. W. Jensen, editors). Proceedings of the International Conference on Dryland Farming. Texas Agricultural Experiment Station, Amarillo, TX. 965 pages.

Ramig, R. E., and L.G. Ekin. 1976. Conservation tillage effects on water storage and crop yield in Walla Walla and Ritzville soils. Oregon Agricultural Experiment Station Special Report 459:15-16.

Ramig, R. E., and L.G. Ekin. 1978. Soil water storage as influenced by tillage and crop residue management. Oregon Agricultural Experiment Station Special Report. Pages 65-68.

Ramig, R. E., and L.G. Ekin. 1984. Effect of stubble management in a wheat-fallow rotation on water conservation and storage in eastern Oregon. Oregon Agricultural Experiment Station Special Report 713:30-33.

Rasmussen, P. E., C.R. Rohde, and N.C. Roager. 1978. Long-term effects of crop residue management on organic matter levels in soil (1931-1976). Oregon Agricultural Experiment Station Special Report. Pages 52-54.

Smiley, R. W., and S. Machado. 2009. *Pratylenchus neglectus* reduces yield of winter wheat in dryland cropping systems. Plant Disease 93:263-271.

Russelle, M. P., and F. E. Bolton. 1978. Loss of seed-zone moisture prior to planting. Oregon Agricultural Experiment Station Special Report. Pages 68-72.

Schillinger, W. F., S. E. Schofstoll, and J. R. Alldredge. 2008. Available water and wheat grain yield relations in a Mediterranean climate. Field Crops Research 109:45-49.

Stephens, D. E., M. M. Oveson, and G. A. Mitchell. 1943. Water Requirement of Wheat at the Sherman Branch Experiment Station. Agricultural Experiment Station Technical Bulletin 1, Oregon State College, Corvallis. 27 pages.

Wilkins, D. E., S. L. Albrecht, and T. R. Johlke. 2003. Chemical fallow seed-zone soil water content in a dry fall. Oregon Agricultural Experiment Station Special Report 1047:64-68.

Wilkins, D. E., C. L. Douglas, Jr., P. E. Rasmussen, and D. A. Haasch. 1983a. Tillage influences on residue incorporation and soil moisture. American Society of Agricultural Engineers Paper No. 83-1026.

Wilkins, D. E., and J. F. Zuzel. 1994. Frozen soil tillage for soil erosion control. Oregon Agricultural Experiment Station Special Report 933:52-55.

Wilkins, D. E., J. F. Zuzel, J. L. Pikul, Jr., and R. W. Smiley. 1991b. Tillage tool for enhancing water infiltration through frozen soil. Pages 393-398. In: Preferential Flow (T. J. Gish and A. Shirmohammadi, editors). American Society of Agricultural Engineers, St. Joseph, MI. 408 pages.

Williams, J. D., D. E. Wilkins, D. K. McCool, L. L. Baarstad, B. L. Klepper, and R. I. Papendick. 1998. A new rainfall simulator for use in low–energy rainfall areas. Applied Engineering in Agriculture 14:243–247.

Williams J. D., S. B. Wuest, and D. S. Robertson. 2015. Soil water and water-use efficiency in no-tillage and sweep tillage winter wheat production in northeastern Oregon. Soil Science Society of America Journal 79:1206-1212.

Williams. J. D., S. B. Wuest, W. F. Schillinger, and H. T. Gollany. 2006. Rotary subsoiling newly planted winter wheat fields to improve infiltration in frozen soil. Soil and Tillage Research 86:141-151.

Wuest, S. B. 2001. Earthworm, infiltration, and tillage relationships in a dryland pea-wheat rotation. Applied Soil Ecology 18:187-192.

Wuest, S. B. 2005. Bias in ponded infiltration estimates due to sample volume and shape. Vadose Zone Journal 4:1183-1190.

Wuest, S. 2007a. Vapour is the principal source of water imbibed by seeds in unsaturated soils. Seed Science Research 17:3-9.

Wuest, S. B. 2007b. Surface versus incorporated residue effects on water-stable aggregates. Soil and Tillage Research 96:124-130.

Wuest, S. B. 2009. Correction of bulk density and sampling method biases using soil mass per unit area. Soil Science Society of America Journal 73:312-316.

Wuest, S. B. 2010. Tillage depth and timing effects on soil water profiles in two semiarid soils. Soil Science Society of America Journal 74:1701-1711.

Wuest, S. B., S. L. Albrecht, and K. W. Skirvin. 1999. Vapor transport vs. seed-soil contact in wheat germination. Agronomy Journal 91:783-787.

Wuest, S. B., T. Caesar-TonThat, S. F. Wright, and J. D. Williams. 2005. Organic matter additions, N, and residue burning effects on infiltration, biological, and physical properties of an intensively tilled silt-loam soil. Soil and Tillage Research 84:154-167.

Wuest, S. B., and L. K. Lutcher. 2013. Soil water potential requirement for germination of winter wheat. Soil Science Society of America Journal 77:279-283.

Wuest, S. B., and W. F. Schillinger. 2011. Evaporation from high residue no-till versus tilled fallow in a dry summer climate. Soil Science Society of America Journal 75:1512-1518.

Wuest, S. B., J. D. Williams, and H. T. Gollany. 2006. Tillage and perennial grass effects on ponded infiltration for seven semi-loess soils. Journal of Soil and Water Conservation 61:218-223.

Wuest, S., J. Williams, and T. Johlke. 2006. Effects of tillage on water infiltration. Oregon Agricultural Experiment Station Special Report 1068:86-92.

Zuzel, J. F., J. L. Pikul, Jr., and R. N. Greenwalt. 1985. Frequency of frozen soil in northcentral Oregon. Oregon Agricultural Experiment Station Special Report 738:1-5.

Chapter 17 - Soil Erosion

Remarkably, the word 'erosion' did not occur in any of the founding documents leading to the establishment of the dryland experiment stations near Moro and Pendleton. Likewise, there was no mention of land degradation through loss of soil. In fact, the first land management procedure was to use a moldboard plow to invert the soil on every acre of land before experiments were initiated at both stations. The following expression was stated in the first Sherman Station Annual Report, in 1910, "*Best of all, the entire station soil was gotten into better tilth by deep plowing and much was summer fallowed …*" (see Appendix 9). The early annual reports from the Sherman Station included only occasional mention of soil that had eroded from certain landscapes or treatments.

The practice of managing soil erosion appears to have been a value that became recognized where forage grasses were being produced. The Pendleton Station was established in 1928, at a time in which there was an extended period of poor wheat crops at both Moro and Pendleton. Wheat produced poorly for five consecutive years from 1929 to 1933. Wheat prices were also at an unprecedented low. The financial situation of many farmers was worse than at any time since 1900. Those circumstances led to a much greater interest in planting forage crops. Scientists at both stations assisted in that effort by planting large forage experiments, beginning in 1931, as described in Chapter 8. In 1932, Dave Stephens, Superintendent of both stations, began collecting agronomic performance data on the forage stands. In 1935, he formalized relationships between the USDA-SCS and the Sherman and Pendleton Stations. The SCS, at Pullman, WA, became the lead agency for planting new nurseries and collection of agronomic data at the stations, as described in Chapter 8. One of the many factors evaluated was the ranking of forages for their ability to control erosion, particularly on steeper slopes. The first documented mention of soil erosion management appears to have been in the 1934 Sherman Station Annual Report. Dave Stephens and Merrill Oveson stated "*… crested wheatgrass planted on a 4-acre parcel of the steepest slopes on the station have practically stopped the water erosion, not only from the land itself but also by capturing the soil from the fallow land above it. Therefore, another 20 acres was planted to crested wheatgrass.*"

Specific research to control soil erosion in eastern Oregon's wheat cropping systems therefore appears to have been secondary to research to improve crop productivity and profitability, and to reduce the rate of loss of organic matter. Although late in being initiated, specific research to stem the loss of soil gained almost immediate importance during the mid-1930s. The formalization of such research to appears to have been a response to a letter, dated April 25, 1933, from Mr. Steve Besse, Vice Director of the OAES, at Corvallis, to Mr. W. A. Rockie, Superintendent of Pacific Northwest Soil Erosion Station, at Pullman, WA. In that letter, Besse stated "*I am pleased to answer your letter of April 8th relative to the establishment of a cooperative terracing project at the Pendleton Field Station. We are authorizing Mr. D. E. Stephens, Superintendent of the Pendleton Field Station, in cooperation with Mr. G. A. Mitchell, Assistant Superintendent, to work with you in developing a cooperative project. Mr. Stephens address is Moro, Oregon. You may communicate with him direct*." George Mitchell responded to Mr. Rockie on August 17. Mitchell stated "*… Our present plan is to suggest three demonstration erosion-control areas because of the multiple problems in this region. The first would be in the foothills of the Blue Mountains representative of the conditions from Pomeroy, Washington to Condon, Oregon, where severe sheet erosion and terrific gullying problems exist. ... This might consist of two or three of the long narrow watersheds, such as Russell and Cottonwood Creeks at Walla Walla, Pine Creek at Weston, Oregon, and Wildhorse Creek at Athena, Oregon. ... The control here would be vegetating (grasses, legumes, and trees) the steeper slopes, planting grass and trees for gully control, and such terracing, strip-cropping and other methods of control as appear advisable. These several watersheds might total up to 50,000 acres. … We particularly want any and all suggestions of erosion-control methods that would be acceptable to farmers, that you feel are feasible. We will appreciate your cooperation.*"

In a report to USDA administrators in Washington, D.C., dated June 30, 1936, George Mitchell submitted a 3-page outline of research at the Pendleton Station. Mitchell described research 1) to prevent loss of surface soil during spring runoff from frozen ground and from heavy rains in early spring, 2) to prevent further heading back of gullies which wreck heavy equipment operating in farm lands, 3) to prevent surface soil losses by sheet erosion that exposes the subsoil and reduces yields, 4) to conserve more winter and spring precipitation for crop use, and 5) to eliminate stubble burning which has caused serious depletion of soil organic matter. The studies included incorporation of grain stubble into the surface soil, crop rotations to keep soil covered during erosion season, planting grasses in draws to bind the soil, and evaluations of tillage systems to increase water infiltration into the soil. He listed the USDA-SCS as a cooperator in several erosion control studies, including a grass nursery and a grass-legume nursery. A summary of key results stated that "*the program of the Soil Conservation Service in the Athena and Squaw Creek areas was already being based upon the results of* [research at] *the Pendleton Field Station*."

As stated in Chapter 16, research on soil and water conservation became strongly amplified and more formalized when additional USDA-ARS soil scientists began to be hired at the Pendleton Station. That facility became justified and funded in response to political pressure coordinated by the Oregon Wheat Commission, as described in Chapter 3. After the facility was opened in 1970, measuring and managing soil erosion became a principal focus of at least eight USDA scientists at Pendleton. They included three agricultural engineers (Dr. Clarence Johnson, Mr. Gerald George and Dr. Dale Wilkins), two hydrologists (Drs. John Zuzel and John Williams), and three soil scientists (Drs. Raymond Allmaras, Joe Pikul and Stewart Wuest). They and others, such as Drs. Ron Rickman and Clyde Douglas, studied the effects of most factors that influence loss of soil. Studies of water infiltration, water storage, soil crusting, tillage pans, silica migration and soil freezing were discussed in Chapter 16. Studies of tillage systems and implements for managing surface residues were discussed in Chapters 5 and 13.

Rill erosion in a winter wheat field with very little crop residue remaining near the surface

Dr. Charles Rohde in gully cut through frozen soil east of the Pendleton Station (1965)

Gullies cut through thawed soil over a lens of frozen soil on near-level land at the Pendleton Station (1997)

The need for the close affiliation between USDA-ARS scientists and staff of the USDA-SCS could not be better described than in an excerpt from the 1965 Sherman Station Annual Report. "*The 1964-65 year has gone down in the record books as a year to be long remembered, from the standpoint of adverse weather conditions and poor crops. Due to lack of soil moisture, seeding was delayed and in some areas many acres were not seeded. December had 6.1 inches of precipitation, which was 4.5 above the 30-year average, and the highest since weather recording started at the Sherman Experiment Station in 1911. On December 22nd and 23rd over two inches of rain fell. Because of frozen ground, and almost a foot of snow at the time, heavy run-off occurred and millions of dollars in damage resulted. Loss of topsoil amounted to many thousands of tons and gully erosion was said to be the worst in the history of the Mid-Columbia area. Thousands of acres of fall-seeded grain were lost due to washing out, smothering and winter-killing. This* *necessitated reseeding in the spring and lack of moisture resulted in extremely poor growing conditions. Nurseries at the Station were either destroyed or had low yields. This was the first time in the history of the station that such a complete loss has occurred.*"

This chapter summarizes research conducted to specifically measure the amount of water running off the landscape, the amount of soil carried in the runoff, and the volume and turbidity of streams and rivers. Some of the same principles affect the amount of dust that becomes airborne from exposed soils during times of high wind speed.

Erosion by Water

Measurement of soil erosion at a site on the slopes of the Blue Mountains, nine miles east of the Pendleton Station, began in 1977 and ended in 1987. The Kirk Farm Erosion Research Site was established on a 16 percent slope to gain a deeper understanding of the processes which influence erosion caused by rain on frozen or snow-covered land, and erosion caused by seepage of water through soil (Johnson et al., 1978). The goal was to collect data that would aid in developing technology for erosion prediction, improved design of diversions, terraces and sediment basins, and better tillage and management practices. The site consisted of six hillside plots managed as pairs of continuous cultivated fallow, or in each phase of a winter wheat-spring crop rotation. The usual spring crop was peas but spring wheat was sometimes planted instead of peas. All plots were plowed during the spring, enabling comparisons of three types of cover during winters; winter wheat seedlings, winter wheat stubble, and fallow. Drs. Clarence Johnson, Raymond Allmaras and Joe Pikul repeatedly measured weather variables, moisture content of the soil profile, runoff rate and amount of soil lost, nitrate and phosphorus in the runoff, and particle size distribution of the soil lost. During the first year, these scientists determined that a single runoff event, following 1.6 inches of rainfall in 24 hours, removed 5.1 tons of soil per acre from the fallow plots, compared to 3.1 tons/acre from winter wheat plots planted directly up and down the hill.

Hillslope configuration for erosion research in Gilliam, Wasco and Sherman counties, and three types of flumes for measuring or collecting runoff water and soil

An objective of research at the Kirk site was collect data to refine the Universal Soil Loss Equation (USLE; first published in 1965) to make it more accurate in the Pacific Northwest. The first objective was to refine the 'cover crop' and 'soil erodibility' factors in the USLE model, and then to change farming practices in the plots to help refine the 'conservation practice' factor in the model. Modified parameters developed from data at the Kirk site were grouped with data from sites in Washington and Idaho. USDA scientists at Pullman provided the leadership for refining the USLE, and proposed refinements were published by McCool et al. (1976, 1987 and 1989). This tri-state effort led to development of an improved model called the Revised Universal Soil Loss Equation (RUSLE), which was itself refined several times (Renard et al., 1997). Components of the newer RUSLE program became incorporated into plant growth and development models developed by Drs. Klepper and Rickman, as described in Chapter 18.

The Pendleton Station also coordinated a 3-year project to demonstrate farming practices that reduce soil erosion as a source of non-point pollution of waterways. In 1972, the U.S. Congress passed the Clean Water Act, which directed the Environmental Protection Agency and the states to identify agricultural-related sources of non-point pollution. One of the studies was conducted in northwest Oregon by the Soil and Water Conservation Districts in Umatilla, Morrow, Gilliam, Sherman and Wasco counties. That coalition identified soil erosion as the most important non-point water pollutant in the region. They recommended 13 'best management' practices for reducing the amount of sediment in runoff water. Federal and state funds were subsequently allocated to demonstrate the value of those practices. In 1978, Mr. Gerald George, of the USDA-SCS, was assigned temporary duty at the Pendleton Station. George coordinated a 5-county demonstration of seven field management systems that could improve water quality by reducing the amount of sediment being removed from fields. His team identified fields that represented typical tillage and management practices for the area, and then used a McCool Rill Meter to measure the amount of soil erosion, and standard weather instruments to measure rainfall intensity and volume, and soil temperature. For three years, they collected runoff samples and measured the amount of sediment being removed every time runoff left each field. Mr. George determined that a single runoff event each year was responsible for removing 60 percent of the annual sediment loss (George, 1981, 1982). George also found that level terraces that didn't breach were totally effective for eliminating soil loss from fields. Breached terraces and terraces with planned outlets were 80 percent effective in removing sediments from water that left the field. Graded terraces of less than one percent slope were 60 to 80 percent effective. Terraces did not stop rill erosion from getting started, but did reduce rill size by reducing rill length down slopes, and retained the sediments within the fields. Conservation tillage methods were found to be more effective than terraces for keeping erosion from being initiated. These tillage practices worked well as long as the rainfall volume and intensity was relatively low, but once runoff started, the stubble on the soil surface did little to remove any of the sediment from the running water. Grassed waterways and buffer strips effectively carried water without contributing additional sediment but had little influence on in-field erosion. Combinations of practices greatly reduced the amount of soil being eroded from fields and watersheds.


Dr. John Zuzel

Drs. John Zuzel and colleagues at the Pendleton Station installed automated erosion monitoring equipment and measured erosion at four of the sites studied by Gerald George. In 1980, 86 percent of the erosion events occurred when soil was frozen (Zuzel et al., 1982). Key factors regulating soil erosion were identified as rain on shallow snow and rain on frozen soil (Zuzel et al., 1983; and Zuzel, 1994). Over a 5-year period (1979-1984), erosion occurred on 28, 14, 11 and 3 occasions at the sites in Wasco, Sherman, Gilliam and Morrow counties, respectively (Zuzel and Pikul, 1990). A majority (54 percent) of those 56 erosion events occurred when soil was frozen and the other 46 percent occurred on thawed soil.

Drs. Zuzel and Pikul used data from the Sherman Station to calibrate a model for predicting soil frost by using data for diurnal air temperatures, snow depth and solar radiation. They then validated the model for winter wheat planted at research sites near the Station. Over a period of five years, they collected data for runoff water, erosion, weather variables, soil temperatures and soil frost. The model correctly predicted frozen soil 80 percent of the time (Zuzel and Pikul, 1990). They then used the model to evaluate 30 years of earlier weather data from the Station. The model predicted freeze-thaw cycles varying from once to seven times a year, and frozen soils ranging from six to 116 days per year, with an average of 57 days. Rain-on-snow events were also associated with 57 percent of the yearly peak discharges at a nearby stream flow gage, and daily precipitation amount and snow depth together accounted for 74 percent of the runoff peaks at the flow gage (Zuzel et al., 1986).

Dr. Clyde Douglas and Paul Rasmussen evaluated the influence of rill erosion and winter wheat yield at five positions on a long slope. They compared the amount of soil lost and wheat tiller density and grain yield in areas without rills and with rills. The comparisons were made at the summit (1 percent slope), shoulder (6 percent), upper back (8 percent), lower back (10 percent) and toe (6 percent) positions of the slope (Douglas and Rasmussen, 1985). Losses of soil and grain yield were approximately equal for east- and west-facing slopes. Loss of soil increased from none at the summit to approximately 317 pounds/acre at the toe position. At mid-slope positions, grain yield was lower in the rilled compared to non-rilled areas. The difference in yield at each of the five slope positions, from top to bottom, was 0, 13, 35, 46 and 25 percent.

As described in Chapter 16, Drs. Dale Wilkins, John Zuzel and John Williams developed a rotary subsoiling tool to determine if punching holes ('pock marks') through frozen soil with a 'spider wheel' could improve water infiltration and reduce soil erosion. The subsoiler was mounted behind a deep chisel shank to assure good penetration of the spider wheel. These scientists compared untreated soil with soil tilled with the shank only, or the shank plus spider wheel. They created replicated plots across frozen slopes of 10 and 13 percent over a 2-year period, applied simulated rainfall, and measured water infiltration, water runoff, and soil sediment collected downslope from the rainfall simulator. It was stated in Chapter 16 that more water penetrated the frozen surface where the tillage shank created fracture channels through the frozen soil, and that the spider wheel did not add benefit to that treatment. They also showed that sediment removal was reduced equally by both of the treatments, and that tilling frozen soil did not reduce productivity of wheat seedlings growing in those planted soils. Wilkins et al. (1991) concluded that pulling a shank across slopes to fracture the frozen soil reduced erosion and conserved more water, as compared to rainwater washing freely off the frozen surface.

Drs. John Williams, Dale Wilkins, Clyde Douglas and Ron Rickman evaluated another type of equipment for its ability to reduce soil erosion. In one pass of the equipment, standing stubble was cut using a harvester header mounted in front of a tractor pulling a moldboard plow. The header moved the stubble laterally onto the surface of soil inverted during the previous pass. The plow then incorporated the remaining residue and weed seeds into the soil. The scientists compared the 'mow-plow' system with moldboard plow and chisel plow treatments at two experimental sites (Jim Duff and Clinton Reeder Farms) near the Pendleton Station (see Chapter 14). They monitored weather conditions and applied three different intensities of simulated rainfall to surfaces of frozen soil on slopes of 5 and 22 percent. The 'rain' was applied into each of the tillage treatments during five freeze-thaw cycles over a 2-year period. Chisel plow performed better than the mow-plow or moldboard plow systems (Williams et al., 2000). The chisel plow treatment delayed the time before 'rain' water started running off the plots and had the least amount of soil sediment accumulating below the plots. However, the mow-plow system was more efficient than the mow-plow for reducing the density of weed seeds and seedlings.

Dr. John Williams

Simulated rainfall used to compare runoff and erosion from frozen soil on hillslopes cultivated using three plow-based tillage systems; mow-plow, moldboard and chisel plow.

Dr. John Williams also evaluated runoff and erosion from the long-term crop residue experiment at the Pendleton Station (see Chapter 6). The residue treatments are in a winter wheat-fallow rotation for which the moldboard plow is the primary implement to prepare fallow during the spring. Wheat stubble remains standing through the winter following grain harvest. The wheat and fallow phases of the rotation lie end-to-end on slopes from 2 to 6 percent. Each plot is 38 × 132 feet. Williams placed shallow furrows between treatments and rotation phases to channel runoff from each plot. He measured runoff from selected treatments that were known to have the greatest differences in amounts of soil carbon and other chemical and physical properties. His measurements included plots that were planted during the autumn as well as plots with standing stubble during the winter. Over a 3-year period, Williams (2004) determined that 82 percent of the runoff events occurred while the soil was not frozen; 74 percent when rain fell onto thawed soil, 4 percent when rain and snowmelt occurred on thawed soil, and 4 percent when snow melted above thawed soil. The remaining 18 percent of erosive events occurred when the soil surface was frozen; 9 percent when it rained on frozen soil, and 9 percent when rain plus snowmelt occurred on frozen soil. He determined that water infiltrated the high-organic matter manured treatment as well as where stubble was standing in the fallowed plots. The greatest amount of water flowed from the low-carbon treatment which, since 1931, had received no fertilizer and the stubble was burned. An important correlation was shown between runoff and the amount of organic matter in soils of various treatments in that experiment.

Dr. Williams leased several watersheds on three commercial farms near the Pendleton Station to study the hydrology of larger landscapes that were managed with different tillage systems and cropping sequences. A 'drainage experiment' at the Reeder Farm was described in Chapter 5. The experiment was conducted on facing watersheds separated by a swale. The site was used to compare erosion in a conventionally tilled (moldboard plow) winter wheat-fallow rotation on a south-facing slope versus a 4-year no-till rotation of winter wheat, spring-planted pea, winter wheat, and chemical fallow on the north-facing slope. The study was conducted for eight years. Measurements were made of the weather, soil water content, water and sediment discharge rates and volumes from each plot, ground cover and crop yield. Runoff and erosion were reported by Williams et al. (2009 and 2014) and crop yields and efficiency of water use were reported by Williams et al. (2009) and Williams and Robertson (2016). The runoff accumulated over eight years in the drainage experiment was 10 times greater from the tilled drainage than the non-tilled drainage. Sediment removal from the tilled drainage was 54 times greater than for the non-tilled drainage. Rills developed where soil was tilled but not where fallow was managed without tillage. About 40 percent of the 22 erosion events accounted for 90 percent of the soil loss, and only two of the 22 erosion events occurred on frozen soil. There was more water in the shallow soil profile, to 1-foot depth, of the chemical fallow than in the tilled fallow. However, wheat yields were equivalent for crops grown in the two tillage systems, and the efficiency of transferring precipitation into crop yield was greater in the tilled fallow than in the chemical fallow. The 'hillslope experiment' at the Jim Duff Farm consisted of no-till treatments from 1998 until 2005. There was no water runoff or soil loss from the steep slope during the time it was managed without tillage. However, both water runoff and soil loss occurred when the experimental area was changed to minimum tillage from 2006 to 2008. Across experiments on all three commercial farms, with plot sizes ranging from a large drainage to a small draw within a field, Williams et al. (2014) determined that erosion rates increased as the amount of ground cover decreased.

Erosion by Wind

Many studies have involved tillage systems that provide rough or residue-covered surfaces to reduce erosion from wind and water. Those studies were described in Chapters 5, 13 and 14. However, comparatively little research at these dryland stations was directed toward measureing wind erosion. Federal and state scientists at Pendleton have communicated the principles of controlling wind erosion. For instance, Dr. Robert Ramig contributed to a publication that described practices to control wind erosion in irrigated sands of the Columbia Basin (Vomocil and Ramig, 1976). Vance Pumphrey published information to promote the use of cover crops and living sods to reduce wind erosion and crop damage (Pumphrey, 1982), and Drs. Stephen Machado and Don Wysocki summarized research and practices to control wind erosion (Papendick, 2004). The latter publication was a report of the Columbia Plateau PM_{10} Project. Drs. Machado and Wysocki also summarized a broad array of research conducted to conserve soil resources (Bista et al., 2017). Before he arrived at the Pendleton Station, Dr. John Williams evaluated effects of microbial crusts on wind erosion from soils in arid landscapes (Williams et al., 1995). He currently has an interest in extending that research to include local soils.

References:

Annual Reports from the Sherman and Pendleton Stations (Appendices 5 and 6)
Letters sent to or from the Station Superintendents

Bista, P., S. Machado, R. Ghimire, G. Yorgey, and D. Wysocki. 2017. Conservation tillage systems. Pages 99-124. In: Advances in Dryland Farming in the Inland Pacific Northwest (G. Yorgey and C. Kruger, editors). Washington State University, Pullman, WA. 614 pages.

Douglas, C. L. Jr., and P.E. Rasmussen. 1985. Rill erosion effect on wheat yield. Oregon Agricultural Experiment Station Special Report 738:12-13.

George, G. O. 1981. Best management practices (BMP) demonstration and evaluation project; five-county north central Oregon area; 1978-1981. Oregon Agricultural Experiment Station Special Report 623:43-44.

George, G. O. 1982. Best Management Practices and Water Quality Demonstration and Evaluation Project: Five-county North Central Area – October 1977 to April 1981. Oregon Agric. Expe. Sta. Special Report 646. 72 pages.

Johnson, C. E., R. R. Allmaras, G. Fischbacher, and J. L. Pikul, Jr. 1978. Measuring soil erosion on the slopes of the Blue Mountains. Oregon Agricultural Experiment Station Special Report. Pages 1-4.

McCool, D. K., L. C. Brown, G. R. Foster, C. K. Mutchler, and L. D. Meyer. 1987. Revised slope steepness factor for the Universal Soil Loss Equation. Transactions of the American Society of Agricultural Engineers 30:1387- 1396.

McCool, D. K., G. R. Foster, C. K. Mutchler, and L. D. Meyer. 1989. Revised slope length factor for the Universal Soil Loss Equation. Transactions of the American Society of Agricultural Engineers 32:1571-1576.

McCool, D. K., R. I. Papendick, and F. L. Brooks. 1976. The Universal Soil Loss Equation as adapted to the Pacific Northwest. Pages 135-147. In. Proceedings of the Third Federal Inter-Agency Sedimentation Conference, Denver CO, March 1976, National Technical Information Service, U.S. Gov. Printing Office, Springfield, VA. 974 pages.

Papendick, R. I. 2004. Farming with the Wind II: Wind Erosion and Air Quality Control on the Columbia Plateau and Columbia Basin. College of Agricultural, Human, and Natural Resource Sciences Special Report XB1042, Washington State University, Pullman. 96 pages.

Pumphrey, F. V. 1982. Crop management and wind erosion. Pages 85-97. In: Crop Production using Cover Crops and Sods as Living Mulches (J. C. Miller, editor). Proceedings of the International Plant Protection Center Document 4S-A-82. Oregon State Univ., Corvallis, OR.

Renard, K. G., G. R. Foster, G. A. Weesies, D. K. McCool, and D. C. Yoder (editors). 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture, Agriculture Handbook No. 703. 404 pages.

Vomocil, J. A., and R. E. Ramig. 1976. Wind erosion control on irrigated Columbia Basin land: A handbook of practices. Oregon State University Extension Service Special Report 466. 24 pages.

Wilkins, D. E., J. F. Zuzel, J. L. Pikul, Jr., and R. W. Smiley. 1991. Tillage tool for enhancing water infiltration through frozen soil. Pages 393-398. In: Preferential Flow (T. J. Gish and A. Shirmohammadi, editors). American Society of Agricultural Engineers, St. Joseph, MI. 408 pages.

Williams, J. D. 2004. Effects of long-term winter wheat, summer fallow residue and nutrient management on field hydrology for a silt loam in north-central Oregon. Soil and Tillage Research 75:109-119.

Williams, J. D., J. P. Dobrowolski, D. A. Gillette, and N. E. West. 1995. Microphytic crust influence on wind erosion. Transactions of the American Society of Agricultural Engineers 38:131-137.

Williams, J. D., H. T. Gollany, M. C. Siemens, S. B. Wuest, and D. S. Long. 2009. Comparison of runoff, soil erosion, and winter wheat yields from no-till and inversion tillage production systems in northeastern Oregon. Journal of Soil and Water Conservation 64:43-52.

Williams, J. D., and D. S. Robertson. 2016. Soil water in small drainages farmed with no-tillage and inversion tillage in northeastern Oregon. Journal of Soil and Water Conservation 71:503-511.

Williams, J. D., D. E. Wilkins, C. L. Douglas, Jr., and R. W. Rickman. 2000. Mow-plow crop residue management influence on soil erosion in north-central Oregon. Soil and Tillage Research 55:71-78.

Williams, J. D., S. B. Wuest, and D. S. Long. 2014. Soil and water conservation in the Pacific Northwest through no-tillage and intensified crop rotations. Journal of Soil and Water Conservation 69:495-504.

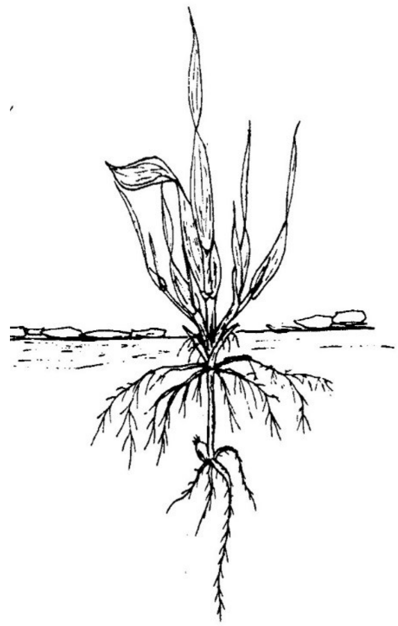
Zuzel, J. F. 1994. Runoff and soil erosion phenomena in the dryland grain growing region of the Pacific Northwest, USA. Trends in Hydrology 1:209-216.

Zuzel, J. F., R. R. Allmaras, and R. Greenwalt. 1982. Runoff and soil erosion on frozen soils in northeastern Oregon. Journal of Soil and Water Conservation 37:351-354.

Zuzel, J. F., R. N. Greenwalt, and R. R. Allmaras. 1983. Rain on snow: shallow, transient snowpacks with frozen soils. Pages 67-75. In: Proceedings of Western Snow Conference (J. Meiman, editor). Vancouver, WA.

Zuzel, J. F., and J. L. Pikul, Jr. 1990. Frozen soil, runoff: and soil erosion research in Northeastern Oregon. Pages 4-10. In: Proceedings of the International Symposium on Frozen Soil Impacts on Agricultural Range and Forest Lands, K. R. Cooley (editor). U.S. Army Corps of Engineer's Cold Regions Research and Engineering Laboratory Special Report 90-1. Hanover, NH.

Zuzel, J. F., J. L. Pikul, Jr., and R. N. Greenwalt. 1986. Point probability distributions of frozen soil. Journal of Climate and Applied Meteorology 25:1681-1686.



Chapter 18 - Plant Growth and Development

The general processes of growth and development of wheat and other plants became well described over the past century. However, many important details were still poorly understood. One area in which information was limited regarded the effects of soil and climatic factors on wheat seed germination, seedling emergence, and development of individual leaves, tillers, heads and roots. It was unclear as to how the development of roots was coordinated with phases of foliar growth and development, or whether the coordination of those processes were closely related to production of wheat heads and grain kernels. It was not known whether club- and common-headed wheat types differed in those relationships. Similar questions could be raised for growth of other crops and of weeds that compete with wheat crops.

These unknowns led scientists at Moro and Pendleton to quantify seed germination, stand establishment, and growth and development of wheat and other plants under different crop management systems and weather. The scientists published results of those studies in more than 80 technical journal papers and more than 80 extension reports. Foremost among these authors were Drs. Betty Klepper and Ronald Rickman, who directed the most comprehensive of the investigations on plant growth and development. The studies of those two scientists alone, led to publication of 72 journal papers and chapters in books (Appendix 3) and 27 extension papers in the Dryland Research Station's Special Report series (Appendix 4). Results of investigations by Klepper and Rickman culminated with the development of climate-driven and user-friendly plant growth models for non-scientists who needed to predict the precise influence of weather on wheat growth and development. An overview of research on plant growth is presented in this chapter.

Seed Germination and Seedling Emergence

The success of a wheat crop often depends on how well the seedlings become established after seeds are planted. Among the important factors that affect seedling establishment are the date and depth of planting. The optimum density of seed planted is also a question of economic importance, because of the high cost for purchasing premium-quality seeds. Another question regards the optimum spacing between plant rows, to allow plants to utilize the maximum amount of sunlight, soil moisture and soil nutrients. Finally, there are many soil or seed amendments that are intended to improve seed germination and seedling emergence. Amendments include fungicides, insecticides, nematicides, micronutrients, starter fertilizer, and water dribbled into the seed row at the time of planting. Many of these procedures and substances have been studied at the Sherman and Pendleton Stations. Research on these treatments are discussed in this section and some are also referenced in Chapters 15, 16 and 19.

Seeding date, rate and depth

Differences in optimal seeding date were expected to vary from year to year due to differences in the amount of water stored in the soil, the timing of rains before and during the planting period, and the soil temperature at the time of planting. The primary unknown was the least risky planting date over the long term. The first date- and rate-of-seeding trials were established at the Sherman Station during 1910. Those studies continued until 1933. During the first two years, it was learned that the first soaking rains in Sherman County differed by 10 calendar weeks; from November 17 in 1910 to September 5 in 1911. It was observed that early-seeded wheat rotted and failed to emerge from the dry soil in 1910. When wheat was planted or replanted after the rains began, the wheat did not emerge until January because the soil was already cold in November and the weather immediately became even colder and snow began to fall.

Within three years, during 1913, the Station began to advise that research showed that the optimal date for seeding varied so greatly from year to year that it was imperative to conduct experiments on methods of seeding early in the season on dry ground. This is because "*on well-kept summer fallow, there is usually enough moisture from three to four inches below the surface mulch to germinate the seed and keep the young plants growing until the rains come*." "*When the seed is planted deep on the dry summer fallow with the ordinary grain drill, the stand is likely to be uneven. This is probably due to two causes: the failure always to put the seed into moist soil and the failure of the small plants to push through the surface dust mulch.*" "*A method might be devised by which the seed can be planted in moist soil in the bottom of small furrows and thus remove much of the dry soil which under ordinary conditions impedes the growth of the young plants*." "*Seeding early, however, will have the disadvantage of making weed control more difficult,* *for when autumn rains come early enough many of the weed seeds germinate and the weeds are killed by cultivation prior to planting winter grains*." This passage from the 1913 Sherman Station Annual Report was the forerunner for the farming system that combined the use of the rod weeder in summer fallow with a deep-furrow drill to plant the crop. This seeding management system was developed, in large part, by the early and intense research effort at the Sherman Station. It is particularly noteworthy that the same basic system is still the prevalent fallow management and planting system in most low-rainfall environments a century later.

One of the earliest date-of-planting experiments at the Sherman Station had four planting dates spread over 46 calendar days; from September 9 to October 25. After six years of testing, in 1919, it was found that the dates on which the winter wheat matured from the different planting dates extended across only 12 calendar days; from July 2 to July 14. The thickest stands were nearly always in the earliest planting dates, with the number of heads diminishing as the planting date was delayed. There were 38 percent fewer wheat heads from the last planting date, as compared to the first planting date. The September plantings each yielded about 34.0 bushels/acre, and the highest yields (38.9 bushels/acre) were from the October 10th planting. The lowest yields (31.2 bushels/acre) were from the October 25th planting. Additional planting dates had been added during 1916, and the 4-year average yields collected until 1919 were always the lowest (21.5 bushels/acre) with plantings on or near November 24.

The optimum rate-of-planting and depth-of-sowing were also optimized during the date-of-planting studies during the early years of the Sherman Station, using four planting dates over a 6-year period from 1914 to 1919. Grain yield increased only slightly when sowing depth was increased from 2- to 5-inch depth; from 21.9 to 22.3 bushels/acre.

The rate and date of seeding experiments were conducted repeatedly after each of the stations were established. The earliest trials were with Turkey wheat. In the 1950s the variety was switched to Elmar. Although early seeding studies with Turkey wheat had shown that lower seeding rates yielded as well as higher rates, and that earlier seeding dates were generally better than later dates, the scientists recognized that those parameters needed to be re-examined whenever there was a complete change of tested variety or agricultural technology. Trials during the 1950s showed that yields of Elmar did not differ for seeding rates that ranged from 30 to 90 pounds per acre. Also, as with Turkey wheat, the highest yields of Elmar were produced from seeding dates during the first two weeks of October. These principals continue to be tested even to the present time. Results of more than 15 experiments over the past century have shown little or no change in experimental outcome, in that results have always been substantially identical to those conducted during the first two decades at the Sherman Station. Specifically, the optimum 'planting window' for achieving maximum wheat yield in this region occurs between the middle of September and the middle of October.

Drs. Klepper and Rickman quantified these concepts by documenting what others had observed but did not quantify. It was confirmed that late-seeded wheat emerged later than seeds planted earlier, and that early-planted wheat had very similar numbers of tillers over a wide range of planting rates. Klepper and Rickman quantified that late-planted wheat produced fewer tillers and fewer heads than early-planted wheat. Their quantitative estimates were based upon the heat units required for each stage in the development of the plant, as discussed later. They provided guidance so that growers could accurately estimate the amount of increase in seeding rate that could be used to compensate for delayed planting dates (Rickman and Klepper, 1987).

Row spacing and drill opener

A row-spacing experiment conducted at the Sherman Station from 1917 to 1919 showed that winter wheat yields were higher when rows were spaced at seven inches (24.6 bushels/acre) compared to 3.5 or 14 inches (21.6 bushels/acre). However, the 14-inch spacing allowed the wheat to mature a little sooner than for the narrower spacings. This finding provided an additional incentive for developing a deep-furrow drill system which could more consistently provide successful stands of winter wheat during early planting dates, before the first soaking rain during the fall.

Side-by-side comparisons of seed drills were studied during the mid-1920s, at a time when nearly all farmers were still using a hoe-type drill. Two photographs were shown in the 1927 Annual Report to report the yield advantages obtained by planting wheat at 12-inch row spacing using a furrow drill, as compared to planting with a 7-inch hoe drill or a 6-inch double disk drill. In all cases, the furrow drill was able to plant into moist soil during the fall and produced higher yields, by 2- to 3-bushels per acre. The wheat planting studies conducted during the first two decades paid dividends in 1929. Due to the difficult planting conditions in the fall of 1928, the furrow drill showed itself to be capable of producing the highest yields of winter wheat in 1929. The hoe drill, which was still being used by most farmers, produced the lowest yields. That research at the Sherman Station led to a rapid transition in the type of drill used by most farmers in the region.

The winter wheat rate- and date-of-sowing experiments and the comparison of the furrow- and hoe-type drills at the Sherman Station were discontinued after the 1933 crop year. One of the experiments had been initiated in 1913, and another in 1926. However, those same experiments were established at the new station at Pendleton, where annual rainfall was higher than at Moro. As with other such fundamental studies to optimize seed germination and seedling stands, drill openers of various designs and spacings continue to be manufactured and studied at the present time. Optimum plant stands have been found to be provided by different drill design and row spacings depending on characteristics such as soil type, soil moisture, soil temperature, surface residue cover, depth of planting, time of year, and others.

At Pendleton, Dr. Dale Wilkins (USDA Agricultural Engineer) placed particular emphasis on the effects of grain drill opener designs on soil moisture retention and soil compaction in the seed zone, on uniformity of seed depth, and on the rate and completeness of seedling emergence. The opener type had important effects on each of the parameters studied. Wilkins et al. (1983) reported that they achieved the best emergence with a modified deep furrow opener that placed over 70 percent of the seeds in contact with soil that contained more than the limiting water content.

The most recent evaluation of row spacing was conducted to determine optimal row spacings for modern deep-furrow drills when planting wheat as deep as eight inches into high residue seedbeds. Drs. Bill Schillinger and Stewart Wuest evaluated agronomic performance of winter wheat planted at six row spacings from 16 to 32 inches. The studies were conducted over three years at one low-rainfall site in Oregon and two in Washington. Comparisons were made for two seeding standards; an equal number of seeds per row at each row spacing, and an equal number of seeds per acre for the six row spacings. With the same number of seeds per row, which planted fewer seeds as the row spacing became wider, the highest grain yield occurred with row spacings of 16 and 18 inches. With the same number of seeds per acre, the grain yield decreased only slightly at the two widest row spacings; 24 and 32 inches. Due to timely in-crop herbicide application, weeds did not become problematic at any row spacing. These scientists concluded that the standard row spacing for modern drills could be widened to at least 20 or 22 inches to facilitate conservation-tillage farming without compromising straw production or grain yield or grain quality (Schillinger and Wuest, 2014).

Seed size and density

Wheat seeds vary in size and density. A frequent question is whether larger or denser seeds produce stronger seedlings and greater grain yields. Three experiments each failed to substantiate the often-held belief that large seeds could be screened from regular seed lots and planted to improve stand establishment, seedling growth and grain yield. Additionally, it was determined that seed sizing for optimum performance would require individual recommendations on seed sizing for each wheat variety. Those findings were important because they eliminated any inclination for the industry to incur the expense of separating seed grain by seed size. The most important of the seed size experiments are highlighted in this synopsis.

The wheat plant produces almost all of its tillers from the plant crown, which forms on the mainstem just below the point where the coleoptile emerges from the soil surface. Drs. Betty Klepper and Ron Rickman examined observations that some wheat seeds produce an additional tiller from the seed. That extra tiller was difficult to distinguish from the mainstem. That phenomenon was therefore called 'twinning' because it looked like there were two mainstems emerging from one seed, which is impossible. Klepper and Rickman determined that twinning only occurred when seedbed conditions were excellent, and 'twins' were two to three times more likely from large seeds than from medium or small seeds (Klepper et al., 1981). Moreover, twinning only occurred when the seed was undamaged. Coleoptiles could emerge from broken seed and the seedlings could become established, but none of the damaged seed produced a seed tiller. Twinning did not occur when damaged seed was planted into a poor seedbed.

A visiting scientist working with Drs. Klepper and Rickman examined the influence of seed reserves on seedling development. They first determined that seed size had a direct association with the development of the coleoptilar tillar on winter wheat (Peterson et al. 1982). Seedlings from small seeds lacked this first-formed and most productive tiller on the wheat plant. They then separated seed lots into three size groups and examined differences in leaf area of seedlings grown from the different seed sizes (Peterson et al. 1989). Growth of the first two leaves was closely correlated with the size of the aleurone layer on each seed. Growth of later-formed leaves were then closely correlated with the size (leaf area) of the first-formed pair of leaves. This research clearly demonstrated that the size of the seed influenced the size of leaves on seedlings. They also dissected portions of the endosperm and examined how the reduced amounts of reserves in the seed affected a wide range of processes related to foliar growth, root growth, and synchronization of plant development.

A student of Dr. Warren Kronstad separated seeds of seven wheat varieties into three size groups and planted equal numbers of seeds per foot of row at Pendleton and Moro. He also examined two additional classes of seeds (small versus large) planted at equal overall seed weight per experimental plot area. Many complex relationships were identified between locations, seedling emergence, number of spikes per plot, number of spikelets per spike, grain kernel weight, plant height, and grain yield (Vahabian and Kronstad, 1983). The student identified both direct and indirect effects of seed size and stand establishment on grain yield under different environmental conditions. Large seed produced increased the number of kernels/spikelet, spikes/plot, percent emergence, and stand count. While small seeds produced smaller plants, they produced the best rates of emergence and stand establishment due to a greater number of seeds planted per unit area, as compared to larger seeds. Nevertheless, seed size and rate of stand establishment did not have any significant effect on the final yield of grain, and the results varied for each variety planted.

Dr. Tom Chastain studied effects of seed size at the Pendleton Station over a two-year period during the early 1990s. He separated the grain into two size groups using two varieties of club wheat, two of common wheat, and two of winter barley. The smallest half and the largest half were planted in equal numbers into field plots that had three different levels of stubble remaining on the soil surface. The different residue levels were accomplished by tilling standing wheat stubble with a chisel, a disk or a moldboard plow, and then preparing the surface by using a skew treader across all primary tillage treatments. Chastain monitored seedling emergence on as many as 20 dates following planting, and also measured crop growth and development, and grain yields. He determined that large seed emerged more rapidly and produced larger plants than small seeds, but seed size generally had no effect on coleoptile length or grain yield (Chastain et al., 1995). He also determined that growth, development, and yield were not affected by different levels of crop residue. However, high amounts of residue did reduce the grain test weight. Chastain concluded that varieties that demonstrate superior emergence, growth, development and yield in low-residue seedbeds have the same superior traits in high-residue seedbeds.

Dr. Clyde Douglas and others at the Pendleton Station conducted a study similar to that described above. This study was conducted during the same two years as the Chastain experiment. Douglas et al. (1993) screened one winter wheat variety to achieve three seed sizes; small, medium or large. Each of the size lots were then further divided on a gravity table to separate them into dense-, medium- or light-weight seeds. Each of those nine seed categories were then compared to seed of the original grain lot (non-separated) in field plots that were either prepared with a moldboard plow or without any tillage. Douglas et al. also concluded that tillage, seed size and seed density had no significant effect on growth or development of wheat plants, or on grain yield when soil moisture was adequate. However, when soil water reserves were marginal, tillage affected growth, development and yield, and seed size and density affected some measures of plant growth but not of grain yield.

Seed quality

Only one study appears to have addressed the quality of seed. Soft white wheat varieties have a high susceptibility to occurrences of pre-harvest sprouting during periods of rainfall or damp weather when crops are mature but still not harvested. This phenomenon initiates the germination process, which leads to reduced milling and baking qualities. Drs. Tom Chastain, Betty Klepper and Dale Wilkins conducted field experiments to determine if wheat affected by pre-harvest sprout could be used as seed grain rather than as food or feed products. Sprouted seed of nine varieties was compared with unsprouted seed of the same variety. Each sprouted seed lot was screened so that the field trials were planted with grain that had fifty percent of the kernels visibly sprouted. These trials were conducted with or without seed treatment with carboxin (Vitavax) fungicide. Measurements were made of crop growth and development, and of grain yield. Stand establishment was strongly affected by different degrees of sprouting (Chastain et al., 1994). Emergence was excellent from seeds without any evidence of pre-harvest sprout. A slight rupture of the seed coat slightly reduced seedling establishment. A major rupture that fully exposed the embryo of the seed led to substantially reduced stand counts. Sprouting of sufficient magnitude to cause a physically damaged embryo led to a near-total lack of seedling emergence. Sprouted seed therefore produced thinner stands and crop growth than normal seed, but there were no differences in final grain yield between stands from sprouted or unsprouted seed. Emergence, growth and yield from sprouted seed was better when the seed was planted shallowly (1.4 inches) than more deeply (3.2 inches). When the amount of sprout was adjusted to fifty percent of each seed lot there was no difference in emergence for the different wheat varieties tested.

Starter fertilizer

The term ‘starter fertilizer’ usually refers to placing small amounts of nitrogen, phosphorus or sulfur placed near the seed at the time of planting. Starter fertilizer is applied separately from the majority of fertilizer applied to achieve optimum crop growth. The amount of fertilizer that can be applied close to the seed must be carefully restricted because higher rates can create localized excesses of salinity, acidity or ammonia evolution, each of which can reduce seed germination, seedling stand and final grain yield. The potential damage depends on the type of starter fertilizer applied, its proximity to the seed, and the physical and chemical properties of the soil. The interest in improving seedling vigor by applying fertilizer in a position where it becomes quickly available to seedling roots began long before the advent of no-till seed drills, which provided the technology to fully adopt this concept.

The first comprehensive studies of starter fertilizer applications at the Pendleton Station were established by USDA scientists in the late 1970s (Rasmussen et al., 1980). Liquid fertilizer solutions were applied directly below the seed using an adapter fitted to a John Deere HZ deep-furrow drill. Four combinations of liquid ammonium nitrate (Solution 20), urea ammonium nitrate (Solution 32), ammonium polyphosphate (10-34-0), and DiSyston (an insecticide) were tested at three locations in Umatilla County (Rasmussen et al., 1980). All of these liquid starter fertilizers delayed seedling emergence by about one day and increased the time required for 80 percent emergence by one to seven days, depending on the fertilizer type and application rate. Little or no stand reduction occurred when ammonium nitrate or ammonium polyphosphate was applied at a low rate. Higher rates, particularly when a combination of Solution 32 and 10-34-0 was applied during a late fall seeding, reduced emergence as much as 20 percent and also reduced the size of plants during the fall. The scientists concluded that certain types of fertilizers reduced stand density in early plantings and that other types of fertilizers reduced stand density in late plantings, and that these effects differed for different types of soils and the rate of fertilizer applied as starter fertilizer. The insecticide reduced stands in sandy soils near Hermiston but had no effect on stand density in the silt loams near Pendleton. Rasmussen et al. (1980) also predicted that a uniformly distributed 20 percent reduction in stand density, from either fertilizer or pesticide toxicity, was unlikely to have a serious effect on grain yield for the semi-dwarf wheat varieties because those varieties have a high capacity to compensate by producing more tillers in areas of thin stands.

Dr. Dale Wilkins, USDA Agricultural Engineer, also studied grain drill opener designs that created the greatest efficiency for placing starter fertilizer with or below the seed (Wilkins et al., 1982). They confirmed that placing starter fertilizer with the seed could reduce seedling emergence and plant growth, depending upon soil conditions at the time of planting. However, they also tested a modified deep furrow opener that placed the fertilizer 2-inches below the seed, a distance of separation that was sufficient to avoid any detrimental effects on emergence even at relatively high rates of fertilizer application. They also confirmed that grain yields were greater when starter fertilizer was placed below the seed.

Twenty-five years later, starter fertilizers were examined again by OSU scientists (Petrie et al., 2005). They evaluated the effects of using a John Deere 1560 double-disk drill modified to allow applications of liquid fertilizers either with the seed or in a ‘deep band’ located two inches below the seed level and midway between drill rows, which were spaced 7.5 inches apart. Three experiments were conducted, two with spring wheat and one with winter wheat. The scientists used seven combinations of urea ammonium nitrate (Solution 32), ammonium polyphosphate (10-34-0), and ammonium thiosulfate (Thio-Sul). The Solution 32 was always placed in the deep band and the Thio-Sul and 10-34-0 were placed either with the seed or in the deep band in different treatments. The scientists confirmed earlier observations that there was a tendency for band applications of fertilizer to reduce the speed of seedling emergence and final stand counts regardless of the fertilizer placement. Additionally, they found that placing Thio-Sul with the seed at the time of planting always reduced stands, head count and grain yield compared to placing the same rate of fertilizer in a band under the seed. Yields of winter wheat were 13 bushels/acre lower when Thio-Sul was placed with the seed, as compared to the same rate applied in the deep band. The greatest yields in those trials resulted from placing Solution 32 and Thio-Sul in the deep band and banding 10-34-0 with the seed.

Smiley et al. (1990a) determined that application of a complex starter fertilizer (N-P-K-S-Fe ratio of 7-7-7-11-11) directly below winter wheat seed improved grain yields in both no-till (10.6 bushels/acre, or 13 percent) and plow-based (1.5 bushels/acre, or 4 percent) tillage systems. While the starter fertilizer also caused Rhizoctonia root rot to become more severe and eyespot to become more prevalent on small seedlings in the no-till system, the increase of those diseases during the seedling stage was heavily overshadowed by the increase in grain production.

Seed treatments (microbial and chemical)

Seed treatments have been evaluated throughout the history of the dryland research stations. All early studies at the Sherman Station evaluated effects of seed treatments on the prevalence of common bunt. It was frequently noted in the annual reports that some treatments reduced the speed of seedling emergence, the density of the seedling stand, and the grain yield. Some of those observations are summarized in Chapter 20.

Considerable testing of seed treatments was conducted at the Sherman Station by Drs. Grabe and Bolton (both from Corvallis) during the late 1980s. They evaluated compounds that were being sold as 'yield-enhancing treatments' for wheat seed. Some of the compounds included a derivative of crab shells (chitosan), a combination of phosphate and adenosine monophosphate, a starch derivative purported to be a 'super slurper', spores of a beneficial fungus suspended in sand, and a magnetization treatment of the wheat seed. None of the compounds increased the yield of winter wheat during two years of testing (Grabe et al., 1988, 1989).

Evaluations of seed treatments became one of the dedicated priorities of Dr. Richard Smiley's research at the Pendleton Station, from 1988 until 2010. Smiley and colleagues published results of seed treatment experiments in 38 refereed technical reports and eight papers in technical journals (see Appendices 3 and 4). While the focus of those experiments were on measurements of damage from diseases, insects and nematodes, and of grain yield and quality, many of the studies also included measurements of seedling emergence, seedling growth, and tillering of plants. Many seed treatment fungicides reduced the number of plants that became established and the number of tillers that developed on individual winter wheat plants (Smiley et al., 1990b; Smiley et al., 1996). Some particularly phytotoxic fungicides, when applied at high but still within-the-label rates, reduced plant stands by as much as 50 percent. Nevertheless, seed treatments rarely reduced or improved the yield of winter wheat, even when those same treatments reduced disease severity on roots of seedlings, reduced the density of plants in the stand, or reduced the production of tillers and therefore the density of wheat heads in the stand. These observations confirmed an earlier study in which Rasmussen et al. (1980) predicted that a uniformly distributed 20 percent reduction in stand density, from fertilizer or pesticide toxicity, was unlikely to have a serious effect on grain yield for semi-dwarf wheat varieties that have a high capacity to compensate by producing more tillers in areas of thin stands. Smiley concluded that the primary necessity for treating wheat seed with fungicides was to protect against a recurrence of smut diseases and to improve seedling emergence from cold or wet soils.

Moisture required for seed germination

For silt loams commonly encountered in the inland Pacific Northwest, the soil around the seed must have a moisture content of about nine percent or more to assure that water does not slow the seed germination and seedling emergence processes (Wilkins et al., 1995). It was assumed that wheat seeds absorbed most of the water they needed for germination as a transfer of liquid water through seed-to-soil contact. The influence of water vapor in soil was less understood, even though it was known that the relative humidity within air spaces in the soil remains near 100 percent through a wide range of soil moisture contents. Drs. Stewart Wuest and Steve Albrecht, USDA at Pendleton, conducted experiments that demonstrated rapid absorption of water and germination of wheat seeds that had no direct contact with soil (Wuest et al., 1999). Adequate amounts of water for seed germination were absorbed as vapor (Wuest, 2002). It was suggested that water vapor rather than seed-to-soil contact should be considered the primary source of water for seeds in unsaturated soils (Wuest, 2007). Drs. Stewart Wuest and Dr. Larry Lutcher, Morrow County Cropping Systems Agronomist, also quantified the amount of water energy required to germinate seeds of several wheat varieties (Wuest and Lutcher, 2013). They determined that most varieties will germinate rapidly when the soil water potential surrounding the seed is above -1.1 MPa, (equivalent to about 6 to 9 percent soil water content in Pacific Northwest silt loams), but will also germinate well, but slowly, in soils as dry as -1.6 MPa (5 to 8 percent water content).

Water injection into the seed row

Time of planting is primarily influenced by moisture in the seed zone. There is often a reduction of seed zone soil moisture near the end of the fallow period. Early fall planting before this residual moisture recedes, ensures emergence but also sometimes allows excessive autumn growth, which depletes soil moisture that could be used by the crop during the critical time of plant development in the spring. Early planting often also is associated with an increase in severity of diseases such as eyespot and Fusarium crown rot. If planting is delayed until after autumn rains wet the soil, seed germination may be hindered by cold soil. A poor stand in winter increases the potential for soil erosion by wind and water.

Dr. Floyd Bolton and students examined the potential for injecting water directly into the seed zone to ensure seed germination and full stand establishment at the optimal planting time, when agronomic growth potential is still high and disease potential is minimal. The first studies were in the greenhouse using soil from the Sherman Station. Soil moisture was adjusted to 5, 7, 9 and 11 percent by weight. The scientists applied the equivalent of 0, 25, 50 and 100 gallons of water per acre. They determined that no amount of added water could ensure germination from soil originally at five percent moisture, and that no amount of water improved emergence from soil with 11 percent miosture. Germination was more rapid but not otherwise improved by adding water to soil at nine percent moisture. In soil at seven percent moisture, no seed emerged without addition of water (Estes and Bolton, 1978).

Bolton then conducted field studies with water injection at the Sherman Station. Injection of water at 120 gallons per acre improved emergence of two wheat varieties by about 25 percent but did not increase tiller density, heads per unit area, or kernel weight. However, the injection did slightly increase the grain yield for Faro but not Stephens winter wheat. Also, water injection improved fall growth and the potential for reducing erosion (Noori-Fard and Bolton, 1981).

Bolton's group then planted into dry soils that were either chemically fallowed or recently harvested; the control seed-zone moistures were 8.4 and 7.9 percent, respectively. They injected water at 0, 50, 100 or 150 gallons per acre at the time of planting. Seed-zone moistures shortly after planting slightly exceeded 11 percent at the highest rate of water injection. Emergence was increasingly improved as the injection rate was increased in both tillage systems; there were 33 percent more emerged seedlings at the highest injection rate compared to the control. Plant height, leaf area and plant dry matter were each improved by 50 to 100 percent by water injection at the highest rate (Noori-Fard and Bolton, 1982). Grain yield was also generally improved by the water injection procedure. Bolton's group concluded that they achieved significant wheat productivity benefits during each of the three crop seasons in which they tested the injection of water to improve seedling emergence from soils with relatively dry seed-zones at the Sherman Station (Noori et al. 1985).

Another variant of the above-mentioned studies was conducted by Dr. Grabe at the Sherman Station (Grabe et al., 1989). He examined the utility of a seed moisturizing process that was developed to improve crop yields in Canada. The process involved soaking wheat seed in water under a vacuum for six minutes and then under positive pressure for another six minutes. The wet seed was then placed in a truck for eight hours to allow the moisture to equilibrate and the seed surfaces to dry so they could be placed into a drill and planted. They compared the commercial process with eight variants of soaking procedures and times, all compared to untreated seed. They found that all soaking procedures increased the seed moisture content but only increased germination slightly more than that for the untreated seed, which at 13 percent moisture had a germination rate of 97 percent. They also found that moisturized seed lost some of its moisture to the soil within the first day after planting, and that by seven days after planting both the moisturized and dry seeds (initially at 25 and 8 percent, respectively) had equilibrated with the moisture content (20 percent) of the soil in which they were planted. Germination was not improved by seed moisturization.

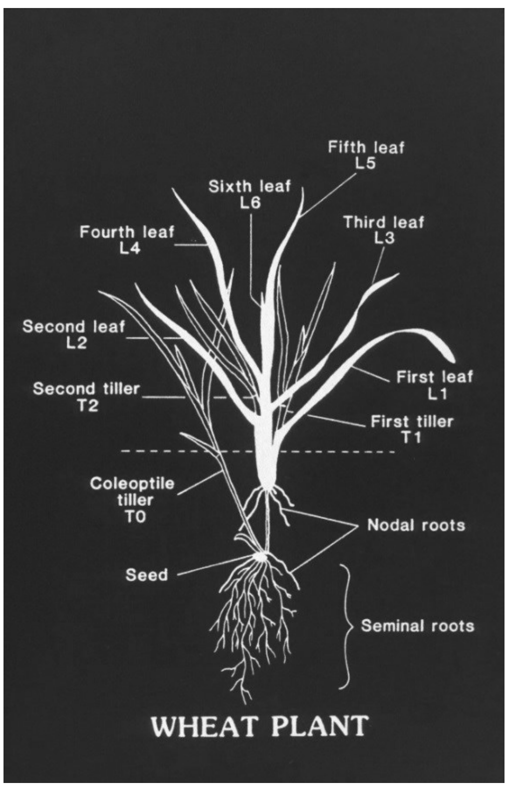
Plant Growth and Development

Drs. Klepper and Rickman, with other colleagues, determined that wheat plants grow and develop every day that the average temperature is above freezing. The rate of development increases as the daily average temperature increases, up to a point when the weather becomes too hot for development. Plant growth stages such as seed germination, coleoptile emergence from the soil surface, growth of leaves, appearance of individual plant tillers, percentage of ground cover, and appearance and size of individual roots could be predicted based upon the depth of planting and accumulation of heat units (growing-degree days; GDD). The GDDs that accumulate each day is calculated by subtracting the freezing point for water (32ºF) from the average of the daily high and daily low temperatures. Klepper and Rickman published nearly 70 technical and 30 extension publications to report results of their research; see Appendices 3 and 4. The huge volume of information they generated far exceeds the capacity for summarizing results of each study. Major concepts are briefly addressed in this section.

Drs. Betty Klepper and Ron Rickman

Klepper and Rickman found that wheat seed germinates and the first roots (seminal roots) become visible in moist soil when 144 GGD have accumulated. If seed was planted into dry soil it is necessary to start the calculation on the date that sufficient rain or irrigation has moistened the soil to at least the depth of planting. After germination, emergence of the coleoptile from the soil surface will occur when 90 GDD have accumulated for each inch of depth that the seed was planted. That means that half of the seedlings that will emerge from seeds planted at 2-inch depth will have done so when 324 GDD have accumulated after the date of planting, or after dry soil was moistened.

Wheat plants produce successive leaves on opposite sides of the stem. Klepper and Rickman assigned numbers to each leaf (L_1, L_2, L_3, etc.) on the main stem and on each tiller. Elongation of the first leaf (L_1) begins at the time when the coleoptile emerges through the soil surface. It took 180 GDD for each leaf on the main stem to elongate to its maximum length. The next younger leaf (L_2) then begins to elongate. This progression occurs upwards from the base of the stem. Tillers develop from buds located at the base of each leaf, under the leaf sheath. The tillers were also numbered; the tiller from the oldest leaf (L_1) is named Tiller 1 (T_1), and so on. Tiller 1 appears when Leaf 4 is elongating. Tiller 2 appears when Leaf 5 is elongating, and so on. You can determine when a plant has quit tillering if you count back from the youngest leaf on the main stem and fail to find a tiller emerging on the fourth leaf downward on the stem. It is possible to fully describe all leaves and tillers even on very complex or bushy wheat plants, although the process becomes much more difficult as plants become more complex.



Nomenclature for individual tillers and leaves of a wheat plant

These USDA scientists determined that three seminal roots emerge from each seed. They assigned a numerical identification to each root and to each branch of each root. They also determined that eliminating just one seminal root, from something like a fertilizer burn, causes permanent and irreparable harm to the plant, including a delay in seedling emergence and a permanent inability of that one-third of the seminal root system to take up water and nutrients. Similar results occur when rooting depth is restricted or is inhibited by layers of soil compaction.

By carefully extracting intact cores of soil, and washing the soil from the roots, Klepper and Rickman determined that each developing plant produces two nodal roots for each tiller that forms. It was therefore possible to count the tillers to gain an insight into the number of roots, which provides information on the capacity of the plant to extract water and nutrients from the soil. These workers assigned a numerical identification to each nodal root and to each branch of each nodal root, and then used accumulated GDD to predict the time at which each nodal root would emerge and when each branch from each nodal root would emerge from the main root axis. The root growth model consistently over-estimated by a factor of two the actually measured number of root branches and the extent of root axes. For modelling purposes, Rickman and Klepper divided the theoretical values by two to achieve good correspondence between the theoretical maximum and the roots actually measured. That adjustment has a profound implication regarding the importance of root diseases in wheat-based farming systems (see Chapter 20). With that adjustment, Rickman and Klepper developed a whole-plant model by merging the foliar and root growth models.

These important plant growth principles allowed others to not only monitor and predict plant development, but to also determine very early in the growing season the number of heads that will be formed on each plant. Moreover, during the tillering stage of plant development, at a time when future wheat heads are still hidden deep within the leaves of each tiller, Klepper and Rickman showed that it was possible to dissect stems to count the number of kernels that would develop on each wheat head. It also became possible to evaluate young seedlings to determine whether the most productive tillers (T_1 and T_2) were formed normally or whether some condition such as an early season drought prevented the formation of one or both of those tillers. This became a powerful tool because stress causes tillers to be omitted or delayed in comparison with unstressed plants, and the numbers of tillers provided an early insight into the number of heads that would be formed. The number of heads is one of the main determinants of grain yield. The USDA team also found that seed size was directly correlated with the sizes of leaves, dry weight of seedlings, number of tillers and number of nodal roots.

Tami Johlke washing soil from roots of wheat grown in the field

Wheat may also develop a tiller (T_0) that emerges from the coleoptile node at the point where the coleoptile emerges from the seed. Seed size, seed quality, and environmental conditions during early seedling growth all have an influence as to whether a T_0 is or is not produced by the plant. The presence of a T_0 was found to be an excellent indicator of a large, high-quality seed, of seedling access to adequate sunlight, of good seedbed conditions at the time of planting, and of a seeding density that caused little interference among seedlings during early seedling growth. However, the T_0 did not contribute significantly to grain yield. As such, the presence of a T_0 was useful for identifying and quantifying effects on plant stress by different tillage systems and planting equipment. Shading of seedlings, such as in stands planted into standing stubble, was another stress factor that greatly reduced the percentage of plants with a T_0.

Research on plant growth also showed that some tillers that had been produced were aborted during the stem elongation and head development stages. Usually, the abortion of tillers follows the 'last on, first off' rule. This occurs mainly on tillers that have three or fewer leaves at the time of stem elongation. Stresses that accelerated the rate of tiller abortion included a limited supply of soil water and insufficient accumulation of mineral nutrients or carbohydrates to sustain the plant in the manner that it had been developing. Abortion of tillers therefore allows the plant to provide greater sustenance to the older, more productive tillers.

The practical usefulness of the retrospective capability and importance of plant growth modeling became particularly evident when a farmer brought a bag of wheat plants to the Pendleton Station to ask whether the scientists could determine why his plants had crinkled leaves. This visit occurred during May. Dr. Rickman quickly determined that all of the

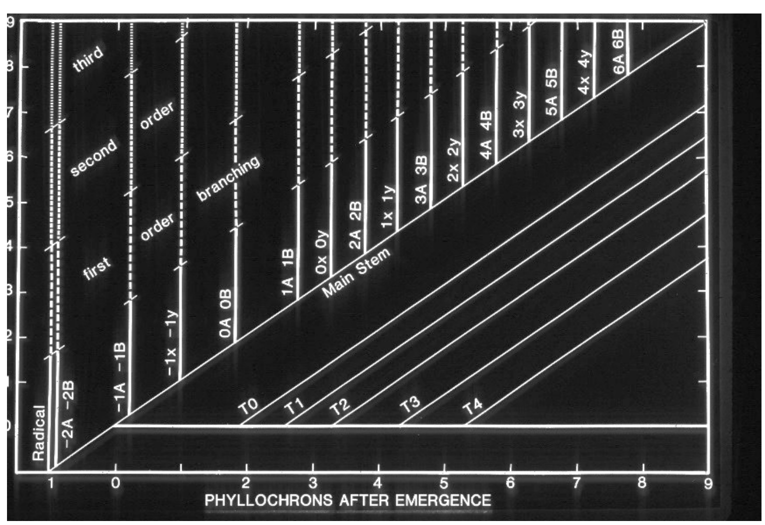


Diagram showing the synchronization of emergences of tillers, nodal roots and root branches crinkling symptoms occurred on the second leaf of each tiller on each plant. He then went to his computer to determine the rate of accumulation of heat units (GDDs) during the previous months. Dr. Rickman then stated that he didn't know what had caused the crinkling, but whatever it was had to have occurred on or about March 12. The visitor examined his field notes and discovered that a herbicide had been applied to that field on that precise date. Weather records then revealed that the nightfollowing the herbicide application had been unseasonably cold. This retrospective insight indicated that an interaction between the herbicide and low temperature was likely to have been the cause for malformation of leaf tissues which were still in embryonic stages of development on March 12.

Klepper et al. (1988) then also published a technical paper that illustrated the use of growing degree days to predict sampling dates for cereal crops at any location. The author of this treatise used these principles to increase travel and research efficiency by predicting the timing at which herbicide applications, samplings of soils and plants, and grain harvest should be performed at research sites as far as 550 miles from Pendleton. The calculations successfully predicted appropriate dates for each of these field management activities in different climatic zones (the Palouse region of eastern Washington, and the upper Snake River plains of southeastern Idaho) during the plant growth stages of seedling emergence, stem elongation, plant heading, anthesis, and full maturation of wheat and barley kernels. Different models for wheat and barley easily and accurately predicted different sampling and harvest dates for each of those crops. As such, Klepper and Rickman's research greatly improved the efficiency of scientists for timing their sampling and treatments of plants at remote research trials. Klepper and Rickman also cooperated with Drs. Don Rydrych and Dan Ball to extend the applicability of their models to the growth and development of downy brome (cheatgrass), jointed goatgrass and several other grass weeds.

Modeling the Synchrony of Root and Shoot Development

The first of Drs. Klepper and Rickman's mathematical models (WHTROOT) described the synchronization of root growth with the development of winter wheat foliage. A more refined, environmentally driven model (MODWht3) synchronized plant growth with the accumulation of growing-degree days (GDD). The GDD calculation is easily accomplished manually but there are many web sites that now provide GDD calculations for each day of the year at each location. Those web sites simply require a person to enter a location of interest and the date on which the seed was planted. Actual GDD up to the present time are shown on the website, and historical data is used to predict GDD accumulation for the remainder of the crop year. Another model (MODCROP) was developed as a collection of input modules that other scientists could easily manipulate or modify, or could even supplement by inserting their own additional input modules, such as for the limiting effects of a root disease, soil acidity, or nutrient deficiency.

In conclusion, farmers and their advisors could use the MODWht3 model to predict growth and development of wheat during the upcoming growing season. They could also use the model to gain a retrospective insight into possible causes for a plant abnormality that became noticeable weeks or even months after the cause of that malady occurred. The same method became useful for describing climate-driven effects on growth and development of jointed goatgrass and other winter annual grass weeds. Many hundreds of farmers, agribusiness agronomists, extension agents, and other scientists have now learned and are using this system to describe wheat plant growth and development.

Influence of Foliar Amendment

In 1992, a paper published in the Proceedings of the National Academy of Science stated that application of wood alcohol (methanol) diluted with water dramatically increased plant growth and crop yield on crops in Arizona. Methanol appeared to increase plant growth by serving as a carbon nutrient and by inhibiting photorespiration, which resulted in greater plant growth while simultaneously reducing the uptake of water by crops. That report attracted immediate interest by scientists in many countries.

In Oregon, the Pendleton-based scientists established research to determine if methanol application could increase productivity of water-limited dryland wheat in the Pacific Northwest, and could do so without requiring more water. Dr. Richard Smiley traveled to Arizona to visit the scientists who published the initial work on methanol. Smiley examined their field research sites. A team of eight scientists at Pendleton then developed a plan of study, which was coordinated by Dr. Steve Albrecht (USDA Soil Microbiologist). They began by hosting the Arizona scientist, who presented a lecture in Pendleton and then helped plan research on major dryland crops in our region. The Pendleton scientists examined different rates and timings of methanol application on winter wheat, spring wheat, spring barley and spring peas over a period of two years. No significant responses were observed for plant growth, grain yield or water uptake. It was concluded that methanol applications were not beneficial for producing dryland crops in this region (Albrecht et al. 1995). Numerous other studies with a wide range of crops across the U.S. led to similar conclusions.

References:

References in Appendices 3 and 4; especially, see the many wheat growth and development papers published by Belford, Klepper, Peterson, Rickman and Wilhelm.

Annual Reports from the Sherman and Pendleton Stations (Appendices 5 and 6)

Albrecht, S. L., C. L. Douglas, Jr., E. L. Klepper, P. E. Rasmussen, R. W. Rickman, R. W. Smiley, D. E. Wilkins, and D. J. Wysocki. 1995. Effects of foliar methanol applications on crop yield. Crop Science 35:1642-1646.

Chastain, T. G., B. L. Klepper, and D. E. Wilkins. 1994. Relationship of wheat seed sprouting severity, planting depth, and seed treatment to emergence and yield. Crop Science 34:508-513.

Chastain, T. G., K. J. Ward, and D. J. Wysocki. 1995. Stand establishment responses of soft white winter wheat to seed bed residue and seed size. Crop Science 35:213-218.

Douglas, C. L. Jr., D.E. Wilkins, R.W. Smiley, and D.B. Churchill. 1993. Tillage, seed size, and seed density effects on early plant development and grain yield of winter wheat. Oregon Agricultural Experiment Station Special Report 909:55-58.

Estes, J. P., and F. E. Bolton. 1978. Water injection into the seed zone as an aid to emergence of dryland cereals. Oregon Agricultural Experiment Station Special Report. Pages 74-75.

Grabe, D. F., F.E. Bolton, and C. Garbacik. 1988. Performance of yield-enhancing agents in winter wheat. Oregon Agricultural Experiment Station Special Report 827:31-32.

Grabe, D. F., F. E. Bolton, C. Garbacik, and J. DeNoma. 1989. Response of winter wheat to yield-enhancing agents. Oregon Agricultural Experiment Station Special Report 840:57-61.

Klepper, B., R.W. Rickman, and C.M. Peterson. 1981. "Twinning" in winter wheat. Oregon Agricultural Experiment Station Special Report 623:65-68.

Klepper, B., R. W. Rickman, J. F. Zuzel, and S. E. Waldman. 1988. Use of growing degree days to project sample dates for cereal crops. Agronomy Journal 80:850-852.

Noori, F., D. N. Moss, and F. E. Bolton. 1985. Water injection at seeding of winter wheat. Agronomy Journal 77:906-908.

Noori-Fard, F., and F.E. Bolton. 1981. The effect of water injection and starter fertilizer on stand establishment and components of yield. Oregon Agricultural Experiment Station Special Report 623:60-62.

Noori-Fard, F., and F.E. Bolton. 1982. The effect of water injection on stand establishment components. Oregon Agricultural Experiment Station Special Report 661:16-18.

Peterson, C. M., B. Klepper, and R. W. Rickman. 1982. Tiller development at the coleoptilar node in winter wheat (*Triticum aestivum* L.). Agronomy Journal 74:781-784.

Peterson, C. M., B. Klepper, and R. W. Rickman. 1989. Seed reserves and seedling development in winter wheat. Agronomy Journal 81:245-251.

Petrie, S., K. Rhinhart, and N. Blake. 2005. Fertilizer placement effects on direct-seed wheat stands and grain yield. Oregon Agricultural Experiment Station Special Report 1061:21-29.

Rasmussen, P. E., D.E. Wilkins, and R.W. Rickman. 1980. Effect of starter fertilizer solutions on wheat emergence, stand and fall growth. Oregon Agricultural Experiment Station Special Report 571:48-52.

Rickman, R.W., and B. Klepper. 1987. Estimating seeding rate increase to compensate for delayed planting. Oregon Agricultural Experiment Station Special Report 797:41-47.

Schillinger, W. R., and S. B. Wuest. 2014. Wide row spacing for deep-furrow planting of winter wheat. Field Crops Research 168:57-64.

Smiley, R. W., L.-M. Patterson, and K. E. L. Rhinhart. 1996b. Fungicide seed treatment effects on emergence of deeply planted winter wheat. Journal of Production Agriculture 9:564-570.

Smiley, R. W., W. Uddin, S. Ott, and K. E. L. Rhinhart. 1990a. Influence of flutolanil and tolclofos-methyl on root and culm diseases of winter wheat. Plant Disease 74:788-791.

Smiley, R. W., D. E. Wilkins, and E. L. Klepper. 1990b. Impact of fungicide seed treatments on Rhizoctonia root rot, take-all, eyespot, and growth of winter wheat. Plant Disease 74:782-787.

Vahabian, M. A., and W. E. Kronstad. 1983. Effects of seed source and seed size on stand establishment, grain yield and yield components of seven wheat cultivars grown under three diverse environments. Pages 1171-1177. In: Proceedings of 6th International Wheat Genetics Symposium, Sadao Sakamoto (editor). Plant Germ-Plasm Institute, Kyoto University, Kyoto, Japan.

Wilkins, D. E., G. A. Muilenburg, R. R. Allmaras, and C. E. Johnson. 1983. Grain-drill opener effects on wheat emergence. Transactions of the American Society of Agricultural Engineers 26:651-655, 660.

Wilkins, D. E., P. E. Rasmussen, B. Klepper, and D. A. Haasch. 1982. Grain drill opener design for fertilizer placement. American Society of Agricultural Engineers Paper No. 82-1516.

Wilkins, D., D. Wysocki, and R. Adelman. 1995. Determining seed-zone soil water content. Oregon Agricultural Experiment Station Special Report 946:53-58.

Wuest, S. 2007. Vapour is the principal source of water imbibed by seeds in unsaturated soils. Seed Science Research 17:3-9.

Wuest, S. B. 2002. Water transfer from soil to seed: The role of vapor transport. Soil Science Society of America Journal 66: 1760-1763.

Wuest, S. B., S. L. Albrecht, and K. W. Skirvin. 1999. Vapor transport vs. seed-soil contact in wheat germination. Agronomy Journal 91:783-787.

Wuest, S. B., and L. K. Lutcher. 2013. Soil water potential requirement for germination of winter wheat. Soil Science Society of America Journal 77:279-283.

Chapter 19 - Soil Microbiology and Ecology

Studies of the ecology of beneficial bacteria, fungi, nematodes and earthworms have occurred only during the past three decades. Prior to that time, scientists conducted studies of microbial-mediated plant residue decomposition processes but not the dynamics of organisms responsible for those processes. For example, since 1910, soil organic carbon concentrations have been monitored in cropping systems as a measure of soil quality, without direct measurements of microbial populations in soil (see Chapter 15).

The first soil microbiology lab at Pendleton was established in 1987, when Dr. Harold Collins became employed as a USDA post-doctoral scientist. A more-refined laboratory was constructed for the microbiology studies during 1990. Collins accepted a permanent position at Michigan State University during 1991. He was succeeded by two formally-appointed USDA soil microbiologists; Drs. Stephan Albrecht and Catherine Reardon (see Appendix 2). Additionally, soils collected from the Sherman and Pendleton Stations have been studied by state or federal microbiologists at Oregon State University (Drs. Peter Bottomley, David Myrold and Stephanie Boyle) and Washington State University (Drs. David Bezdicek, Lloyd Elliott and Ann Kennedy). Further studies of soils from long-term experiments at Pendleton have been conducted in as many as six other states and three other nations.

Collins, Albrecht and Reardon studied microbes and microbe-mediated processes affected by different types of tillage, crop rotations, soil amendments and other management variables. Specific studies focused upon such factors as carbon dioxide emissions from soil, dynamics of soil organic carbon pools, nitrogen mineralization, plant residue decomposition, and microbial dynamics and interactions. These three soil microbiologists also served as important members of interdisciplinary research teams. From 1987 to 2018, more than one-third of the publications from the three Pendleton-based microbiologists were not directly related to microbes or microbial functions in soil. Many contributions of these soil microbiologists are therefore incorporated into topics discussed in Chapters 15, 18 and 20. Nevertheless, their multi-faceted support services and contributions are clearly evident in the publication record; see Appendices 3 and 4.

This chapter presents a summary of specific soil microbiological and ecological studies by the soil microbiologists and selected other scientists at Pendleton.

Plant Residue Decomposition

The search for methods to decrease the amount and intensity of tillage has been a continuous goal for research at the dryland research stations and centers. One of the hindrances to reduced tillage was that long straw segments lying near the surface do not become fragile quickly enough to break easily when encountered by seed drills in 2-year winter wheat-summer fallow rotations in the Pacific Northwest. Straw lying crosswise to the direction of seeding caused drills to become fouled, requiring farmers to get off the tractor to manually remove the soil and residue that caused the drill to become inoperable. Residues that remain near or at the soil surface are very dry during the summer months when the soil temperature is most favorable for microbial activity, and are wet over prolonged periods during the winter months when the temperature is least favorable for microbial activity. Surface residues therefore remain intact for much longer periods in the Pacific Northwest than in regions, such as the Great Plains, where there is about the same amount of total rainfall each year but a significant amount of that rainfall occurs during the summer when both temperature and moisture are favorable for residue decomposition during the same time period.

Overall effects of temperature, moisture, pH and the soil microbiota on the process of residue decomposition were reasonably well known. It was also known that decomposition of residue by microorganisms occurs in three phases. The initial phase is relatively rapid and involves oxidation of compounds such as sugars, amino acids and organic acids. The second phase is considerably slower and involves oxidation of the relatively more resilient compounds such as cellulose and hemicellulose. The third phase is very slow during the mineralization of very resistant compounds such as lignin. However, growers and scientists in the Pacific Northwest recognized that the search for methods to decrease the number of tillage trips across a field was being influenced by different rates of straw decomposition depending on the wheat variety and the crop management conditions. Additional clarity of these processes was required.

USDA scientists at Pendleton quantified the effects of wheat cropping systems on rates of straw decomposition from the late-1970s to early-1990s. Dr. Clyde Douglas and, later, Drs. Harold Collins and Stephan Albrecht were the key scientists that led those investigations. They published papers in technical journals (Appendix 3) and in research center's Special Reports (Appendix 4).

Douglas found that straw decomposition rates were more than twice as rapid when the straw contained adequate concentrations of nitrogen and sulfur, and that straw buried deeply enough to reside in moist, warm fallow soil decomposed three- to eight-times more rapidly than straw that remained above the soil surface. Also, straw elevated or standing above the soil surface decomposed more slowly than straw lying on the soil surface (Douglas et al., 1980). Douglas also documented that most of the straw decomposition occurred during the fall and early spring, when both temperature and moisture were favorable for microbial activity. He also showed that straw decomposed more slowly in cropped fields than in fallow fields. Further, Douglas and Rickman (1992) showed that the rate of decomposition could be calculated and predicted for individual fields by using an equation that included a knowledge of the initial nitrogen content of the straw, the water content at the depth of straw placement in soil, and the accumulated heat units (growing-degree days) calculated from air temperature. Douglas also showed that different rates of decomposition by different wheat and barley varieties was essentially a reflection of the initial nitrogen content of the straw, and correlated well with the amount of nitrogen and sulfur mineralized from decaying residue. Douglas then also showed that the same principles applied to decomposition of canola stems and pods, and to stems of Russian thistle (Douglas and Wysocki, 1994; Douglas et al., 1999). All of the early work on residue decomposition at Pendleton was achieved by measuring the rate of weight loss for various residue components that had been placed inside soft nylon bags (tulle bridal-veil cloth) that were then incubated on the soil surface or at various depths in soil.

These findings provided important guidelines for determining in advance the amount of wheat or thistle residue that would remain at any specific time, which is an important consideration for minimizing the amount of soil erosion that will occur on fields. It also allows growers and advisors or regulators to determine if growers are in compliance with requirements of conservation compliance contracts. Other scientists have also used some of Douglas' data to estimate the rate at which wheat stems deteriorate and fall over in the standing stubble of no-till systems (Steiner et al., 1994). Information of that type is important for estimating wind erosion and snow trapping, and for studies of the micrometeorology and energy balance near the surfaces of fields. It was determined that the rate of stems falling over depended upon the rate of stem deterioration near the soil surface, which was a function of seasonal rainfall and temperature, and then upon the presence of a physical event (high wind, snow, wild animals, etc.) that would cause the stems to fall over after the stem base was sufficiently deteriorated.

Carbon Dioxide Emission from Soil

The first microbiologist at Pendleton, Dr. Harold Collins, and two microbiologists from Washington State University expanded the earlier residue decomposition studies by examining the weight and chemical composition of various components of wheat residue, and by measuring the volume of carbon dioxide emitted from soil during the residue decomposition process (Collins et al., 1990b). At 20 sampling sites they found that the ratio of weights of tissue from stems, leaf sheaths, chaff and leaf blades averaged 37:30:20:13. They also determined that the total weight of wheat residue was directly correlated with grain yield, that leaf blade tissue decomposed much more rapidly than tissue from stems or head-chaff components, and that leaf sheath tissue decomposed at an intermediate rate. The rate of decomposition for these components of residue was closely associated with concentrations of carbohydrates (sugars), lignin, nitrogen and sulfur in the different tissues. However, when all of the components were mixed in the ratio shown above, before burial in soil, the rate of tissue decomposition was 25 percent greater than would have been predicted by calculating rates from individual components.

In another study, Collins et al. (1990a) combined the measurements of weight loss and carbon dioxide emission to examine the rate of stem tissue decomposition during a one-year interval in which the straw was lying on the soil surface under natural field conditions. They determined that the rate of weight loss was most rapid during the first month (12 percent) and then averaged 0.05 percent per day for the remaining 11 months, for a total loss of 33 percent weight during the year. They also quantified the rates of loss for various components over the one-year period, including total nitrogen, soluble carbon and carbohydrate (17, 73 and 66 percent, respectively). The amount of soluble carbon in the fresh stem tissue had an important effect on the initial stage of decomposition but was of little or no importance thereafter.

Collecting air over soil surface to measure emission of greenhouse gases

These findings allowed the soil microbiologists to construct mathematical models to estimate the rate of residue decomposition in carbon sequestration (CQUESTR) models that were described in Chapter 15. That new information was also very important for evaluating practices for protecting soil against wind and water erosion.

Dr. Stephan Albrecht measured rates of respiration in soil seven times over a one-year period (Albrecht et al., 1996). Samples were collected from the top three inches of a fallow field and were taken into the laboratory. After a carbon source (sugar) was added, the rate of carbon dioxide emission was determined while the soils were being incubated in the laboratory. Soil respiration was very low in the late fall and winter months and increased rapidly during April and early May. Respiration then abruptly declined as soils became dry during late June and became further reduced as soils became colder in the fall. The rate of respiration was much more closely associated with soil temperature than with soil water content.

The emission of carbon dioxide from soil was also used to examine differences among five no-till treatments on a commercial farm near Dixie, Washington (Albrecht and Wilkins, 1998). The treatments included two types of seed drills (Yielder and Flexi-Coil) and different combinations of urea, anhydrous ammonia, and starter fertilizer (N-P-K-S). The drills caused soil disturbance to different soil depths; five inches for the Yielder and two inches for the FlexiCoil. Carbon dioxide was collected and measured in chambers placed directly onto the recently planted soil. Emissions were measured by connecting the chambers to a portable gas analyzer. Albrecht and Wilkins found no differences in carbon dioxide emission from the two seed drills and the various fertilizer treatments.

Yielder No-till Drill: an early version of a drill designed for planting into non-cultivated soil

Drs. Wuest and Albrecht constructed a chamber to measure carbon dioxide concentrations in soil before, during and after tillage (Wuest et al., 2003). The chamber contained a soil core and a propeller-like blade to mix the soil during a simulated a tillage operation. The scientists monitored the amount of carbon dioxide evolved over the course of their experiments. They found that each soil emitted peak emissions immediately after the tillage and that the rate at which the emissions returned to pre-tillage conditions depended upon the soil and its previous management. Their work showed that measurements of carbon dioxide emissions needed to be instantaneous at the time of tillage in order to assure accurate information for that process. Even a short delay (less than a minute) in placing an instrument above tilled soil would be unlikely to detect the peak period of carbon dioxide emission after the tillage event.

Microbial Dynamics in Soil

Measurement of carbon dioxide emission from soil is just one of the methods used to estimate microbial metabolic activity in soil. Other methods include measuring the concentration of a fluorescent dye that was cleaved from a compound (fluorescein diacetate) added to soil, measuring the activities of specific enzymes in soil, and measuring the concentration of adenosine triphosphate in soil. Numerous methods are also available to identify major groups of microorganisms, such as directly isolating microorganisms onto culture plates in the laboratory, and by employing various biochemical and molecular methods.

Collins et al. (1992) initiated these studies at Pendleton by measuring the numbers of bacteria, fungi and actinomycetes, and the total microbial biomass, in treatments of the long-term experiments at Pendleton (see Chapter 6). They determined that total soil microbial biomass was two times greater in annually cropped soils (annual wheat or barley, or a wheat-pea rotation) than in a wheat-fallow rotation, except where animal manure had been applied during each fallow period. When compared to the microbial biomass in the perennial grass pasture, the biomass was 50 percent lower in annually cropped soils and 75 percent lower in wheat-fallow soils, except where manure was applied. The microbial biomass in the wheat-fallow rotation was also lower where straw was burned compared to where straw was incorporated by inversion tillage (moldboard plow). Other aspects of that work demonstrated the changes in biomass of total bacteria and total fungi doubled during the winter and decreased drastically as soil dried during the spring. In contrast, the biomass of actinomycetes remained relatively stable from season to season. This study confirmed and quantified the premise that microbial dynamics would be strongly influenced by crop management practices, by fallow, and by season of the year.

Similar studies using direct isolations of microbes was conducted by Dr. Stephan Albrecht (Boyle and Albrecht, 2002b). They determined that microbial numbers were much greater in the manured treatment of the crop residue experiment (see Chapter 6) than in the stubble-burned, non-fertilized treatment, which had similar numbers as the grass pasture and the no-till annual winter wheat. They also found that microbial numbers were greater where the rate of fertilizer application was highest in no-till winter wheat plots, and that there were no differences among fertilizer rates in conventionally tilled (moldboard plow) plots.

Albrecht followed that work with studies to determine if soil microbial activity in the long-term plots could be effectively studied by measuring the metabolism of a precursor to a fluorescent dye that was added to soil (Smith and Albrecht, 2001). He determined that the rate of evolution of the dye was slowest in the unfertilized crop residue treatment, higher in the manure treatment, and highest in a heavily fertilized no-till winter wheat field.

Nitrogen Fixation

A diverse group of soil-inhabiting bacteria capture atmospheric nitrogen and convert it into ammonium ions. The ammonium can be further converted to nitrate. Both ammonium and nitrate can be taken up by plants. The nitrogen-fixing bacteria, called diazotrophs, therefore help to reduce the amount of nitrogenous fertilizer that needs to be applied. Dr. Catherine Reardon and colleagues estimated the population of nitrogen fixers in soil by extracting DNA from soil and measuring the concentration of a gene (*nifH*) that is required for production of the nitrogenase enzyme (Reardon et al. 2014). They measured that gene in two cropping systems; a 29-year-old wheat-fallow rotation and a 1-year-old wheat-pea rotation. In each system, they made measurements at three soil-depth intervals and in treatments that had either been fertilized with 160 pound of N/acre, or had received no fertilizer. Results were highly variable over the two years of study. Seasonal variability therefore had a greater influence on nitrogen-fixing bacteria than plant species (wheat or pea), fertilizer application, total N, total organic C, or soil pH.

Soil Amendments

Application of nitrogenous fertilizers cause soils to become acidified over time (see Chapter 15). Acidification has become a problem in areas where higher rates of nitrogenous fertilizers have been applied for six or more decades. When soils are plowed, the acidification is distributed through the entire plow layer. When soils are managed without tillage, fertilizers are applied through seed drills that incorporate the fertilizer at shallow depths of about 2 to 4 inches. In no-till fields, the surface few inches of soil becomes much more acidic than soil below five inches. Application of lime to correct soil acidity has been practiced and studied mostly on soils that are cultivated between crops, which ensures thorough distribution of the lime to the depth of cultivation. Lime moves downward very slowly in uncultivated soil. In fields that are not cultivated, lime applied to the soil surface becomes incorporated very shallowly and slowly by infrequent passes of a no-till drill. Likewise, if lime is applied through the drill, the lime becomes concentrated into bands corresponding to the configuration and spacing of seed drill openers.

Dr. Stephan Albrecht participated in a study that determined the microbial responses to applications of lime at various depths and concentrations into no-till soils (Fuentes et al., 2006). Application of lime neutralized soil acidity and increased the release of nitrate-nitrogen, indicating more favorable conditions for nitrogen mineralization and nitrification. The microbial biomass and the evolution of carbon dioxide from microbial respiration each increased at shallow soil depths that received lime. However, this was considered a potential detriment in no-till soils where carbon storage (carbon sequestration) is considered a beneficial ecological process compared to conventionally tilled soils. The authors concluded that placement of lime below the soil surface was effective for correcting soil acidity under no-till management, and that liming increased microbial activity and the release of organic nitrogen and carbon.

Soil microbes control the decomposition of plant residues and are known to be sensitive to the type of carbon placed into the soil. Drs. Reardon and Wuest conducted a study to determine if the type of carbon amendment in a no-till wheat system created long-lasting changes in microbial community structure or activity. They evaluated microbial communities in non-amended soil compared to soils amended with nine sources of carbon; cotton, sucrose, wheat residue, composted wheat residue, brassica residue, wood sawdust, alfalfa, manure, or biosolids from municipal waste. The amendments were applied for five consecutive years and were studied under five different cropping scenarios; annual winter wheat (5 crops), winter wheat-fallow rotation (3 crops), continuous fallow, perennial tall fescue, or a combination winter- or spring-planted brassica species. All crop residues were retained at the surface of this no-till experiment. Soils were collected for evaluation before the amendments began to be applied (in 2002), and after the third crop of winter wheat in a wheat-fallow rotation (in 2007). The soil was then fallowed, without tillage, for another 3½ years to monitor changes in soil organic carbon. The field was then managed as a winter wheat-fallow rotation for another two crop cycles, after which it was sampled again in 2011 and 2013. The scientists evaluated fungal and bacterial abundance and composition, and the biochemical activities associated with cycling of carbon, phosphorus, sulfur and nitrogen (Wuest and Gollany, 2013; Wuest and Reardon, 2016, and Reardon and Wuest, 2016). They determined that most microbial communities were very similar in all ten of the surface-applied carbon treatments. There were no important differences in bacterial populations in response to the carbon or cropping treatments. However, application of wood sawdust or sugar, and planting of tall fescue, increased the size and structure of the fungal population in comparison to all other amendments or cropping patterns. The carbon-to-nitrogen ratio was increased during the 5-year cropping cycle by applications of biosolid, manure or sawdust, indicating that amendments applied at the same carbon rate can have variable effects on the amount of carbon that accumulates in soil. Also, the roots of crops were more important than the above-ground residues for the accumulation of soil organic carbon. Continuous cropping to wheat or tall fescue, or applications of animal or human waste led to the greatest accumulation of soil organic carbon, and the positive effects of those treatments remained stable for many years of continuous fallow after the end of the treatments.

Earthworms

Only one sequence of studies appears to have been conducted with earthworms. Dr. Stewart Wuest examined the population of earthworms and earthworm cocoons in four tillage treatments of the long-term wheat-pea rotation at the Pendleton Station (see Chapter 6). Over a two-year period, he determined that a minimum tillage treatment (cultivated by sweep and skew treader to a depth of one inch) had 2- to 5-times more earthworms than were found in deeper tillage treatments that received primary tillage by using a chisel plow or moldboard plow (Wuest, 2001a). Moreover, there were 22- to 27-times more earthworm cocoons in the minimum tillage treatment. Wuest also demonstrated that the minimum tillage treatment had water infiltration rates that were far greater than those in soils tilled with a chisel plow (2 times greater) or moldboard plow (3 times greater).

In a companion study, Wuest (2001b) examined the density of biopores and the distribution of biopore diameter in the upper 30 inches of the soil profile. Wuest compared sizes and densities of biopores in soils that had not been tilled for one or 17 years, and had received no fertilizer or 120 pounds of N/acre for each crop. Biopores were assumed to be connected to the soil surface and to have a role in movement of gases and water through the soil profile. More than 99 percent of the biopores were of very small diameter and were likely caused by growth of wheat roots. There was no influence of tillage or fertilizer on the small-diameter biopores. There were far more large-diameter biopores in long-term no-till soil than for the 1-year period without tillage, and the amount of fertilizer had no effect on this finding. The larger biopores in no-till soil were presumed to have been created by earthworms.

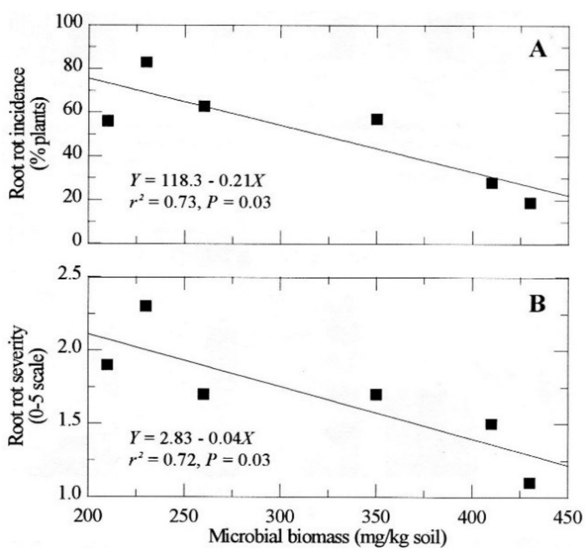
Beneficial Nematodes

Only one study has focused on the population of beneficial nematodes. Over a five-year period, Dr. Richard Smiley evaluated the populations of non-plant parasitic and plant-parasitic nematodes in seven counties in Oregon and four in Washington. The survey included 130 non-irrigated fields and 18 irrigated fields. Results pertaining to plant-parasitic nematodes are discussed in Chapters 16 and 20.

Non-parasitic nematodes were detected in all samples and were generally present in significant proportions of the nematode fauna at all sites (Smiley, 2004b). Population densities of non-parasites ranged from 36 to 42,909 nematodes per pound of soil. The proportion of non-parasites ranged from 2 to 100 percent of the total nematode population. There was no relationship between the densities of non-parasites and parasites. This was an expected result because those two groups of nematodes feed on different substrates and therefore do not compete for food or other resources. Densities of non-parasites were higher in no-till than in cultivated winter wheat-fallow rotations. However, in three-year rotations or in fields cropped annually, the densities did not differ among tillage systems. Also, there was no difference among populations in annual cereals compared to where cereals were rotated with broadleaf crops.

Associations between Microbes and Root Pathogens

The relationship between microbial populations and root diseases was evaluated indirectly in four long-term experiments at Pendleton (see Chapter 6). Samples of wheat roots were collected over a period of three years. Observations were made for root diseases such as Fusarium crown rot, Rhizoctonia root rot, Pythium root rot, take-all, and eyespot. When reporting the results of that survey, Smiley et al. (1996) made comparisons of diseases and earlier microbial assessments in the same plots (Collins et al., 1992). There was an inverse relationship between the total soil microbial biomass and the incidence and severity of Rhizoctonia root rot in treatments sampled from three of the long-term experiment, as shown in the chart. Smiley et al. (1996) also suggested that Pythium root rot was suppressed in response to a combination of greater microbial biomass and greater microbial species distribution in some treatments and experiments. Take-all disease of roots is generally unaffected by stubble burning in short-term experiments but was more severe in burned than unburned plots of the long-term experiment. Smiley et al. suggested that effects of stubble burning on microbial properties of soil could be responsible for these unexpected results for the take-all disease in the long-term experiment.



Relationship between soil microbial biomass and incidence (top) and severity (bottom) of Rhizoctonia root rot in four long-term experiments at Pendleton

Current Soil Microbiological Research

The focus of Dr. Reardon's soil microbiology program is to develop new knowledge about microbial benefits derived from crop rotations. Compared to traditional wheat-fallow rotations, she is determining whether wheat-oilseed rotations provide benefits from changes such as increased nitrogen availability, improved soil structure, or reduction in plant diseases. To achieve her goal, she uses molecular and traditional methods to compare changes in the microbial diversity, microbial composition and microbial function. This requires the identification of fungal and bacterial populations, and determining how, or if, Brassica oilseed crops inhibit or "biofumigate" soil communities at the root:soil interface; e.g., the rhizosphere.

References:

Annual Reports from the Sherman and Pendleton Stations (Appendices 5 and 6)

Boyle, S. A., and S. L. Albrecht. 2002. Enumerating soil bacterial populations in the CBARC long-term plots. Oregon Agricultural Experiment Station Special Report 1040:81-87.

Collins, H. P., L. F. Elliott, and R. I. Papendick. 1990a. Wheat straw decomposition and changes in decomposability during field exposure. Soil Science Society of America Journal 54:1013-1016.

Collins, H. P., L. F. Elliott, R. W. Rickman, D. F. Bezdicek, and R. I. Papendick. 1990b. Decomposition and interactions among wheat residue components. Soil Science Society of America Journal 54:780-785.

Collins, H. P., P. E. Rasmussen, and C. L. Douglas, Jr. 1992. Crop rotation and residue management effects on soil carbon and microbial dynamics. Soil Science Society of America Journal 56:783-788.

Albrecht, S. L., C. L. Douglas, Jr., and K. W. Skirvin. 1996. Carbon dioxide release from the soil during residue decomposition. Oregon Agricultural Experiment Station Special Report 961:97-101.

Albrecht, S. L., and D. E. Wilkins. 1998. Carbon dioxide emission from soils following direct seeding. Oregon Agricultural Experiment Station Special Report 98

Douglas, C. L., Jr., R. R. Allmaras, P. E. Rasmussen, R. E. Ramig, and N. C. Roager, Jr. 1980. Wheat straw composition and placement effects on decomposition in dryland agriculture of the Pacific Northwest. Soil Science Society of America Journal 44:833-837.

Douglas, C. L., Jr., P. M. Chevalier, B. Klepper, A. G. Ogg, Jr., and P. E. Rasmussen. 1999. Conservation cropping systems and their management. Pages 73-95. In: Conservation farming in the United States: The methods and accomplishments of the STEEP Program (E. L. Michalson, R. I. Papendick, and J. E. Carlson, editors). CRC Press, Boca Raton, FL.

Douglas, C. L. Jr., and R. W. Rickman. 1992. Estimating crop residue decomposition from air temperature, initial nitrogen content, and residue placement. Soil Science Society of America Journal 56:272-278.

Douglas, C. L., Jr., and D.J. Wysocki. 1994. Decomposition of canola residue. Oregon Agricultural Experiment Station Special Report 933:56-57.

Fuentes, J. P., D. F. Bezdicek, M. Flury, S. Albrecht, and J. L. Smith. 2006. Microbial activity affected by lime in a long term no-till soil. Soil and Tillage Research 88:123-131.

Reardon, C. L., H. T. Gollany, and S. B. Wuest. 2014a. Diazotroph community structure and abundance in wheat-fallow and wheat-pea crop rotations. Soil Biology and Biochemistry 69:406-412.

Reardon, C. L., and S. B. Wuest. 2016. Soil amendments yield persisting effects on the microbial communities - a 7-year study. Applied Soil Ecology 101:107-116.

Smiley, R. W., H. P. Collins, and P. E. Rasmussen. 1996. Diseases of wheat in long-term agronomic experiments at Pendleton, Oregon. Plant Disease 80:813-820.

Smiley, R. W., K. Merrifield, L.-M. Patterson, R. G. Whittaker, J. A. Gourlie, and S. A. Easley. 2004. Nematodes in dryland field crops in the semiarid Pacific Northwest USA. Journal of Nematology 36:54-68.

Smith, D., and S. Albrecht. 2001. Fluorscent diacetate hydrolysis as a method of determining soil microbial activity in Columbia Basin silty loam soils. Oregon Agricultural Experiment Station Special Report 1026:111-117.

Steiner, J. L., H. H. Schomberg, C. L. Douglas, Jr., and A. L. Black. 1994. Standing stem persistence in no-tillage small grain fields. Agronomy Journal 86:76-81.

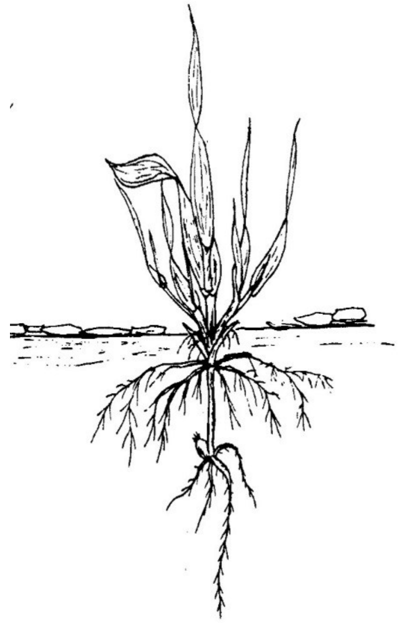
Wuest, S. B. 2001a. Earthworm, infiltration, and tillage relationships in a dryland pea-wheat rotation. Applied Soil Ecology 18:187-192.

Wuest, S. B. 2001b. Soil biopore estimation: Effects of tillage, nitrogen, and photographic resolution. Soil and Tillage Research 62:111-116.

Wuest, S. B., D. Durr, and S. L. Albrecht. 2003. Carbon dioxide flux measurement during simulated tillage. Agronomy Journal 95:715-718.

Wuest, S. B., and H. T. Gollany. 2013. Soil organic carbon and nitrogen after application of nine organic amendments. Soil Science Society of America Journal 77:237-245.

Wuest, S. B., and C. L. Reardon. 2016. Surface and root inputs produce different carbon/phosphorus ratios in soil. Soil Science Society of America Journal 80:463-471.



Chapter 20 - Plant Diseases

Common bunt, which has also been called stinking smut, was the most important wheat disease when the Sherman and Pendleton stations were being established. Extensive and pioneering research on that disease was conducted at both stations. Among other diseases detected on the stations during the first six decades, only stripe rust, eyespot and common root rot became targets of specific research. All local studies of plant diseases prior to 1985 were coordinated by agronomists and cereal breeders at the Sherman and Pendleton stations. They worked closely with plant pathologists from Corvallis OR, Pullman and Prosser WA, or Washington, D.C.

During the first three decades of the Sherman Station, USDA and state experiment station mycologists and pathologists from other locations visited the Sherman Station and collected plant samples throughout the county and region. In particular, scientists from Pullman, WA, Corvallis, OR, Fargo, ND, and Washington, D.C. sampled crops at many locations to identify whatever pathogens or diseases they could find. A large number of smut and rust pathogens were collected and identified from grasses native to the region. While not discussed further, older publications commonly cite Sherman County as the location where early collections were made for specific fungi. These mycological collections of historic importance are exemplified by listings in books such as by Sprague (1950), Fischer (1953) and Farr et al. (1989).

Dr. Richard Smiley

Dr. Richard Smiley was the first plant pathologist assigned to the dryland experiment stations in eastern Oregon. He had previously been a professor at Cornell University (Ithaca, NY). Starting in 1985, as Superintendent of the Sherman and Pendleton Stations, Smiley performed administrative duties but also conducted research and extension on the biology and control of root and crown diseases until he retired in 2015. The current, plant pathologist was Dr. Christina Hagerty, who came to Pendleton in 2017, after completing her doctoral dissertation at Oregon State University.

Additional studies of diseases were performed by Dr. John Kraft, a USDA Plant Pathologist at Prosser, WA. Kraft collaborated extensively with USDA scientists at Pendleton, focusing on studies of tillage systems and genetic resistance to control root diseases of green processing pea. Since 1985, additional studies have been conducted at both stations by Dr. Christopher Mundt, an Oregon State University plant pathologist at Corvallis. Mundt's research has not been published or reported in a written format, and is therefore is not included in this summary.


Dr. Christina Hagerty

An important component of Dr. Smiley's research from 1985 until 2015 involved screenings of seed treatment fungicides and nematicides, and sometimes also insecticides applied as seed treatments or foliar sprays. Results of several hundred such tests were reported in the technical journal '*Fungicide and Nematicide Tests*' (these reports are not referenced in this book), and sometimes also in the Special Report series published by the research centers (see Appendix 4). Tests were conducted in all eight northcentral and northeast counties of Oregon, extending westward to Friend and Tygh Valley in Wasco County, eastward to Flora and Joseph in Wallowa County, and southward to Haines and Pocahontas in Baker County. Tests were also conducted in seven counties of eastern Washington (Klickitat, Benton, Walla Walla, Columbia, Garfield, Adams and Whitman), and in one county of eastern Idaho (Fremont). Target diseases for the chemical control trials included dwarf bunt, flag smut, eyespot, Cephalosporium stripe, pink snow mold, gray snow mold, take-all, Rhizoctonia root rot, Fusarium crown rot, Pythium root rot, root-lesion nematode, and cereal cyst nematode.

More comprehensive research on specific diseases is summarized in the following pages.

Symptoms Mostly in Stems, Foliage or Heads

Common bunt

The first mention of common bunt in Pacific Northwest occurred during an extension field tour of wheat breeding nurseries in 1892, near Garfield, Washington. Research on the biology and control of common bunt was well underway during the 1910s, through the research of Dr. F. D. Heald at the State College of Washington, in Pullman.

In 1910, when the Sherman Station was established, it was already known that common bunt was caused by two different pathogens; *Tilletia tritici* and *T. levis*. It had also been discovered that the pathogen's spores were transmitted as a contaminant on the surface of wheat seeds, and that the adhering fungal spores could be killed by treating the seed with copper sulfate (bluestone) or formaldehyde (Heald, 1915). However, the disease rapidly increased in importance, and it could not be adequately controlled by knowledge and technology available at that time. Much additional work was needed to combat the common bunt problem.

The first research at the Sherman Station, in 1912, revealed that "*Some seed lots were sensitive to the strength of the solution of formalin used to treat the seed, some of which was badly smutted*." The following year, an evaluation of seed treatment on stand establishment showed that formalin reduced seedling emergence when the seed was planted into dry soil or was planted when temperatures were low during the late fall. Additional experiments on the Station and in Washington were established to determine the effects of 1) concentrations of formalin and bluestone on seed germination, 2) treatment temperature on fungicidal properties, 3) solution standing time on gain or loss of solution strength, 4) planting treated seed into cold or dry soil, 5) planting treated seed while wet or after a thorough drying, 6) washing treated grain after spores on the seed surface had been killed, 7) different methods of drying the seed after treatment, 8) speed of the thrasher's separator cylinder on cracking and scratching of the seed coat.

Common bunt of wheat; wheat grains are replaced by bunt balls containing millions of tiny smut spores

The field tests required to answer those questions were very labor intensive. Workers counted the number of smutted heads and total heads per unit of area in replicated stands of wheat planted from each treatment. Results of each test were used to modify treatment procedures, and to provide rapid communications with growers and seed suppliers during field tours and through technical bulletins (Woolman, 1914; Stephens and Woolman, 1922; Woolman and Humphrey, 1924; Tisdale et al., 1925). In summaries of those early years, McGregor (1982) stated that, "*In the 1920's scientists had given the Columbia Plateau the dubious honor of being the wheat smut center of the world.*" The report of the USDA-BPI plant disease survey for 1922 estimated losses from common bunt to be about a half million dollars in Umatilla County alone (Haskell and Wood, 1923). Other overviews of the early years were presented in Chapter 2, and in Brumfeld (1968) and Scheuerman and McGregor (2013).

It was quickly realized that some varieties became more heavily damaged than others. Large numbers of varieties began to be screened at the Sherman Station to determine the extent to which genetic differences in susceptibility to common bunt might be present. By 1916, genetic crosses were being made at the Station, to hybridize the best agronomic varieties with the most smut-resistant varieties.

Stephens frequent communicated with Professor H. P. Barss, Plant Pathologist at Oregon Agricultural College. In a response to Barss' question, Stephens responded with a 2-page letter dated August 25, 1917. That letter included the observations that "*The stinking smut of wheat is by far the most serious. Climatic conditions are sufficiently different from those at Pullman to make the work done by the Washington Experiment Station in smut investigations of little value when applied to this section. We have found it considerable easier to get a stand of wheat if the seed has not been treated for smut, and a good many farmers last year sowed with no treatment. If some method of treating seed could be found whereby the smut spores could be killed with no injury to the seed germ, it would much simplify the smut problem in this section*." … "*Farmers here usually treat their seed for smut, formaldehyde being the most common* *disinfectant used. ... keeping spring wheat free from smut. Some varieties of barley ... are quite susceptible to covered smut, and the disease is more difficult to control than the stinking smut of wheat. We have found ... that with careful treatment (skimming and floating off the smut balls) the covered smut of barley can be practically eliminated. The usual method of treatment (dipping in bags) is not generally successful*."

Shortly thereafter, in a letter dated September 7, 1917, Dr. Heald, at Washington State College, asked Dave Stephens to provide samples from at least ten of the most promising commercial varieties at the Sherman Station. Heald stated that "*The investigation of wheat smut is one of the important projects of this experiment station*." In October, USDA pathologists at Corvallis asked Stephens to send a bushel and a half of Turkey C.I. 1558 wheat seed that had been grown at the Station, for use in a study that would be conducted simultaneously at Corvallis and Moro. The next spring, on May 13, 1918, Professor Barss, at Corvallis, nominated Dave Stephens as Oregon's representative on the War Emergency Board of Plant Pathologists, a U.S. registry of personnel who could provide "*valuable emergency information ... on the control of bunt in wheat*."

By 1920 the cereal breeding and cereal disease investigations were being conducted at a comprehensive level at Moro, with "*some exceedingly important results* [being] *obtained in connection with production of smut resistant wheat varieties*." The 1921 Sherman Station Annual Report stated "*A number of pure lines of winter wheats have proved exceedingly smut resistant. Further hybridization of the standard commercial wheat varieties with the new smut resistant wheats needs to be done to achieve high yields along with resistance to smut. The cereal disease work at the Branch Station was conducted by Mr. H. M. Woolman*."

During 1921, the smut nursery was expanded significantly. It included many progeny from crosses made in 1916 and 1917. The trials included some Crimean wheat selections and progeny of crosses made by Woolman at the Sherman Station and by Dr. Edward F. Gaines at Washington State College. Gaines was a Harvard-trained geneticist who succeeded William Jasper Spillman, at Pullman. Dr. Orville Vogel was trained by Gaines, and became his successor. Gaines' goal was to identify lines that could be safely sown without the formaldehyde seed treatment. Some of the wheats at the Sherman Station were tested with seed artificially infested with smut spores, which made this the first field experiment in Oregon where seed or soil was inoculated with a specific plant pathogen.

Progress was also made with seed treatments. Some of that work was contributed by the wheat industry. For instance, an article in the East Oregonian newspaper, on May 14, 1918, reported that "*A small working model of a vitrioling machine invented by L. D. Smith of Helix* [Umatilla County, OR] *is on display at the office of County Agent M. S. Shrock. The machine is for use in treating seed for smut which is one of the biggest enemies Umatilla farmers have to fight. Formerly the seed wheat especially in this county has been treated by hand with blue vitriol or formaldehyde solutions. This was a long and tedious job for the men with large acreages, but with Mr. Smith's machine, one man can do as much work as four or five in the same length of time. The wheat is poured into a perforated tank which rests in a vat of the liquid. The smut balls rise to the top and are skimmed off. After immersing, the inner tank is windlassed to a certain height from where it is tipped and the wheat or other grain poured into sacks*."

A seed treatment trial was conducted with eleven treatments during 1923. Seed of four wheat varieties was artificially infested with smut spores and then treated or left untreated (checks). Agronomic growth and development data were reported, including the occurrence of smut. Smut incidence varied from 4 to 88 percent, depending on treatment. This was the first finding that the current industry standard (soaking seed in formaldehyde) could be replaced by a dry dusting with copper carbonate. The formaldehyde method was very disagreeable for workers and often caused reduced seed germination and seedling emergence. In contrast, the copper carbonate method was less toxic to workers and did not cause such severe phytotoxic reactions in the treated plants. Unfortunately, when non-inoculated seed was planted directly into smut-infested soil, none of the treatments provided more than 50 percent reduction in the occurrence of smut. That demonstration enabled the scientists at the Sherman Station to be among the first internationally to surmise that smut spores must also be surviving in soil, and were therefore a second source of pathogen inoculum capable of causing the disease. It therefore became doubly important to find sources of genetic resistance because the seed treatments at that time killed the smut spores on treated seed but did not kill the spores residing in soil.

On January 15, 1925, Dave Stephens responded to the authors of a bulletin being prepared for publication as a USDA Farmers Bulletin. His input assisted in estimating the cost of common bunt to the farmers for the 1923 crop year. Data was based on shipments to wheat export terminals in Portland and

Astoria. The loss from smut in Oregon alone was calculated at $1,694,202, based on 26,807,000 bushels produced. The loss from all three Pacific Northwest states was $7,499,628.

Dr. Gaines released the variety 'Ridit' as the first smut-resistant wheat variety in the Pacific Northwest. By 1926, most of the winter wheat varieties carried some level of resistance to common bunt. But the smut-resistant wheats typically did not produce high yields and they generally had poor milling and baking qualities.

Another historic discovery was made at the Sherman Station during 1927. The Annual Report stated that "*Inasmuch as emphasis during the past few years has been placed on the production by pure-line selection and hybridization of smut resistant winter wheat varieties, a discovery this year of the apparent existence of a different strain or physiological form of stinking smut, is a matter of much importance*." "*Hitherto immune and highly resistant varieties, like Martin, White Odessa and Ridit, smutted quite badly when the seed was inoculated before sowing with smut spores obtained from a sample of smut furnished by Mr. A. F. Nelson of the Grain Supervising Office of the U.S. Department of Agriculture at Portland. The smut was obtained from a car of smutty wheat received at Portland from the Palouse section of Washington. No record was made of the original shipping point of this carload of smutty wheat.*"

In a letter dated July 28, 1927, Dave Stephens wrote to Dr. Edward C. Johnson, Director of the Washington Agricultural Experiment Station, at Pullman. Stephens stated "… *our results have been in very close agreement with those obtained by Dr. Gaines. This season, however, our previous results were completely upset. Last fall we were short of smut spores for inoculation and sent to Mr. A. F. Nelson of the Grain Supervision Office of the Department in Portland for some smutballs. He sent us a supply which he stated was obtained from a carload of wheat shipped to Portland from the Palouse section of Washington. … In our smut trials this year, varieties hitherto immune or highly resistant, smutted quite badly. … It appears, therefore that we got hold of a different form of smut from that which the Oregon and Washington Stations have been using heretofore in their smut-resistance trials. … I think it exceedingly important to the wheat growing industry for someone to determine just how widely this form of smut is distributed in the Northwest. There may also be other forms. If so, we should know it. … I think this discovery of a new form of stinking smut is a matter of enough importance to … determine just how many strains or forms of stinking smut we may have in the Northwest and where they are located*." Stephens continues at length to further define the problem he has discovered and the collaborations he has already generated for further screening of the smuts in a greenhouse at the USDA's Arlington Farm in Virginia.

The smut spores used as inoculum at the Station were clearly different than any previously used on the Station. A region-wide investigation was therefore initiated by the state experiment stations in Oregon and Washington, in cooperation with the USDA, to determine if there was further evidence for the existence of other new physiological forms of the smut. If so, extreme care would need to be exercised to not spread any new forms to farmer's fields from the wheat grown on the Station. Also, if new forms were present, the entire breeding program for producing smut-resistant wheat would need to be enlarged and to become more complex. The Sherman Station obviously had a leading and very important role in that discovery. Stephens wrote a 2-page letter to Professor E. G. Schafer, Washington Agricultural College, Pullman on August 9, 1927. In that letter he stated "… *with reference to the probable occurrence of a new form of stinking smut. I am of the opinion that we have a new physiological form, which probably has been in existence in the Northwest for a long time. … Perhaps in our breeding work, we did not begin at the beginning and determine whether there was in existence more than one form of stinking smut. I should not be at all surprised if we find more than two forms of Tilletia tritici, and perhaps also several forms of Tilletia levis. … I think we should begin this fall and collect smut from many different sources and try this smut on our resistant varieties. I think the Washington, Oregon, and Idaho Stations, and the Department of Agriculture, should cooperate and do a little more intensive work for the next few years on this smut problem. … What do you think about it?*"

Also, on August 11, 1927, Stephens wrote a 3-page letter to Max A. McCall, Cereal Investigations, Washington, D.C. He stated that " … *with reference to the smut situation. I do not think it at all probably that the particular type of smut we have this year came from the German importation by Dr. Gaines. I think that this would be quite impossible. I rather suspect that we have two and possibly more forms of smut in the Northwest, and have had them for many, many years*." The many further communications on this issue were of the type captured by the following excerpt from a letter, dated August 29, 1927, to Dave Stephens, from V. F. Tapke, Associate Physiologist, Cereal Smut Investigations, Cereal Crops and Diseases Department, Bureau of Plant Industry, Washington, D. C.: "*On my return to Washington, D.C. I learned* *that you are in favor of a more comprehensive test than that planned by Dr. Gaines and myself to determine the possible existence of physiological forms in Tilletia tritici in the Pacific Northwest*." … "*We will leave it entirely with you to determine the extent of the differential nursery to be used in the physiologic form test*."

David Stephens clearly became a coordinator for additional information on this issue. On September 1, 1927, he wrote a letter to Dr. C. R. Ball, Bureau of Plant Industry in Washington, D.C. The following excerpts were taken from that lengthy letter: "*Now comes Mr. Bayles with information that he no doubt has still another physiologic form of bunt in Montana. ... Mr. Bayles informs me that a Mr. Rodenheir at St. Paul, Minnesota, has definitely proved that there are several forms of stinking smut. Is this man working in cooperation with the Office? If so, I would like to get some information about his work. ... From present appearances, it seems that each locality has a problem of its own in breeding wheat varieties for bunt resistance. I am of the opinion that it would be wise to place this work in the charge of an experienced pathologist of the Office, so as to have the work coordinated and carried on effectively*." Stephens then continued with a suggested structure for a research program of that type.

Stephens made a listing of the smut samples he collected for use in the smut-resistant trials at Moro during the fall of 1927. The list included the place collected, collector, and species name of each pathogen (*Tilletia laevis* or *T. tritici*) for 90 separate smut cultures collected from all over the U.S., including a large number of sites in Oregon, Washington and Idaho. The listing also included cultures from California, Arizona, Montana, Colorado, South Dakota, Nebraska, Kansas, New York, Minnesota, Illinois, Texas, Indiana, Wisconsin, Pennsylvania, and Iowa. Many of these collections were submitted directly to Dave Stephens, as evidenced by the original letters of transmittal accompanying those collections. He screened the smut collection at the Sherman Station until about 1930, as evidenced in 1-page letter to Stephens from Dr. Harold H. Flor, USDA Plant Pathologist at Washington State University. The letter, dated August 30, 1930 included the following statements: "*I am enclosing a summary of data obtained in our cooperative physiologic smut nursery at Moro ... The results ... were quite similar ... and I believe that the additional data secured does not warrant continuing them for another year as they necessitate an excessive amount of work*." "*While I was at Moro, …*"

The discovery of an additional race of the fungus had important practical consequences for research at the Station. A field of pure-line smut-resistant Oro winter wheat had been planted during 1926 to supply seed to farmers during the fall of 1927. Some of that field had been dusted with smut spores to assure that the Oro variety was indeed resistant. The source of the smut spores had been from the smutty wheat from the Palouse region. Some of the plants in the field of Oro became smutted. Instead of being used for seed wheat, all smutted plants from all smut experiments were pulled and burned, except for a few saved for spore material for the 1927-1928 experiments. Grain from the field of seed wheat was destroyed because it could not be distributed to farmers.

A much larger smut nursery was grown during 1928 to determine beyond any doubt whether new specialized strains of the bunt truly existed. These tests at Moro and Corvallis proved that there were several physiologic forms of bunt, some of which severely attacked varieties that had previously been considered resistant.

When the Pendleton Station became established, George Mitchell, Assistant Superintendent, immediately began working in close collaboration with Dr. Harold Flor, USDA Plant Pathologist at Washington State University. In 1930, Flor established several 76-row common bunt-screening nurseries at the Pendleton and Sherman Stations. His goal was to distinguish among the physiologic races of the pathogen occurring naturally in the region. He also established additional nurseries to determine the resistance of wheat entries in variety trials to spores of locally-collected bunt collections that he inoculated into soil at the time of planting. Flor traveled to both dryland stations in Oregon to plant the seed, score the disease on maturing plants, and harvest the trials. He also established the winter wheat nurseries during the following two winter wheat seasons.

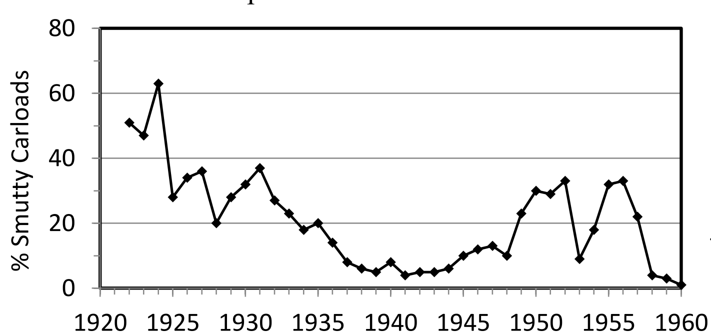
The emphasis on common bunt and other smuts was strongly amplified in 1931, at which time Dr. C. Stewart Holton was appointed to study the problem in a USDA-BPI, Division of Cereal Crops and Diseases laboratory on the campus of the State College of Washington. The College then also hired a smut pathologist, Dr. George W. Fischer, in 1934. After three years at Pullman, WA, Harold Flor moved to Fargo, ND to conduct research on a rust disease of flax. At that location, during the 1940s, Flor developed the gene-for-gene concept to explain the genetic interactions between the rust pathogen and the flax host plant. His concept provided the basis for research on genetics of host-pathogen interactions for at least the next seven decades. While at North Dakota **State University**, Flor continued to interact with agronomists at the Pendleton and Sherman Stations. He even traveled by rail to the Pendleton Station in May 1943 to acquire an old USDA pickup truck that was no longer being used. The staff at Pendleton installed new tires and made sure the pickup would still run before Flor arrived to drive it back to Fargo.

The problem with common bunt gradually subsided from the 1920s to the early 1940s. The percentages of smutty carloads then increased substantially during the late 1940s and peaked again during the 1950s before being brought under control by about 1960. The strong decline in smutty shipments delivered to Columbia River export terminals during the mid-1930s was attributed to the broad acceptance of newly-released smut resistant varieties such as Ridit (in 1923), Oro (1927), Rio (1931), and Rex (1933). Ridit was developed by Dr. Gaines, at Washington State College, and Oro, Rio and Rex were important releases from the Sherman Station. However, in 1938, 70 percent of the acreage in Sherman County was still being planted to Turkey Red, and only four percent was planted to Rex (Hall, 1959). The resurgence of smutty shipments during the 1950s was attributed to the increasing production of higher-yielding but susceptible varieties that were planted without adequate chemical treatment. Elgin was produced on 70 percent of the acreage in Sherman County during 1947 and, because of its susceptibility to common bunt, Elgin was almost completely abandoned by 1953 (Hall, 1959). The most popular varieties produced in Sherman County during the late 1950s were Elmar and Omar. During the 1910s and 1950s it was common for combines in eastern Washington and parts of Oregon to stir up clouds of black smut spores. Twenty-nine million bushels of wheat were downgraded graded as 'smutty' during a single year in the 1950s. The Spokane Daily Chronicle, on January 11, 1956, reported an article with the headline "Smut Takes Record Toll of Wheat in Northwest" (Brumfeld, 1968).

Smut spores were also dangerous. When accumulated as a spore mass, that mixture could explode by spontaneous combustion. Smut explosions ruined a considerable number of combines and started many wildfires in grain fields, as was illustrated in Brumfeld (1968). The Sherman Station became involved as a resource for information. For instance, on July 26, 1915, George Hyslop, Instructor in Soils and Crops, Oregon Agricultural College, wrote a letter to Dave Stephens. The USDA was seeking information regarding the frequency and magnitude of the explosions. An excerpt from Hyslop's letter is as follows: "*I am in receipt of a letter to President Kerr by Carl D. Alsbery, Chief of the Bureau of Chemistry, regarding smut explosions in the Northwest. The Bureau … and … are investigating the problem of smut explosions … As you undoubtedly know of smut explosions and know in what locality smut explosions occur most frequently and possibly have had opportunity to investigate some of them personally, … pleased if you write to Mr. Price and give him full information … on such an occasion*." The prevalence of the explosions coincided with the years during which smut epidemics were greatest, during the 1910s and 1950s.

Wheat varieties under test during the late 1940s included many selections from crosses made during 1942 and 1944, with progeny being retained during advancement through early generation testing. The main objective was to select for yield in varieties that carry resistance to both common smut and dwarf bunt. But the smut problem became greater than the amount of research that could be mustered at that time. In the 1948 Sherman Station Annual Report it was stated that "*The percent of smutty wheat was higher this year than last year's all-time high. Larger acreages of smut-susceptible varieties and careless treating methods are blamed for this increase*." "*The acreage of fall sown Orfed was increased in Sherman and Morrow counties. Many farmers are interested in Orfed for its smut resistance. Orfed appears to be inferior to Elgin in yield, however*."

The 1952 Station Report stated that "*The increase in smut infection of wheat in northern Sherman County the past few years, regardless of improved seed treatment methods and facilities, has led to the belief that some smut infection is occurring from soil infection. This is further indicated by the distribution of the smut incident in the field. Often the percent of smut is greater near the edge of a field with was badly infected the previous year. This is particularly true if the wheat field files to the windward side of a stubble field. The percent of smut decreases*



% smutty train-car loads delivered to Portland export terminals *as the distance from the stubble field increases. Evidently smut spores are distributed in the fallow at harvest time to lie there until the wheat is seeded that fall. This type of smut infection is not controlled satisfactorily by seed treatment*." The Station staff therefore set out field trials to test new seed treatments at three sites near Wasco. The state of the art treatments at that time were mercury-containing fungicides such as Ceresan and Agrox. During 1952 at a field two miles south of Klondike, 80 percent of the heads were infected by smut, mostly due to soil contamination. Some breeding lines on the station had 50 percent smutted heads while others had only a trace of smut.

In response to the foregoing reports and similar reports from other western states, the federal program at Pullman was again amplified in 1953, coinciding with a renaming of the Bureau of Plant Industries as the Agricultural Research Service. Three additional smut pathologists (Drs. Lawrence H. Purdy, Edward I. Kendrick, and James A. Hoffmann) were appointed at Pullman, and a similar appointment was made at Corvallis (Dr. Robert J. Metzger). Those new smut pathologists joined Holton, Heald, and Fischer in working very closely with the wheat breeders across the western U.S. Each of them also developed a particularly close alliance with Dr. Charles Rohde, at Pendleton.

One novel attempt at killing the common bunt pathogen was reported in 1954 by David Bayer, the first weed scientist at Pendleton. He attempted to control field bindweed (morning glory) at the Crow Pilot Farm and Russian knapweed on a commercial farm by injecting an electrical current into the soil (see Chapter 21). He and others had hoped that the treatment would also kill soil-inhabiting spores of the common bunt pathogen. The 'Electrovator' treatments were ineffective against the pathogen as well as the weeds.

During the 1950s and 1960s the USDA-ARS Regional Smut Research Laboratory at Pullman made extensive use of experimental lands available at the Sherman and Pendleton Stations. The Pendleton Station was used extensively for examining race specificity on an assortment of wheat varieties selected to distinguish among races of the pathogens. One experiment at Pendleton during 1957 examined new collections of smut spores from 139 commercial fields in Oregon, Washington, Idaho and Montana. In addition to identifying races and geographical areas where they were prevalent, the smut scientists from Pullman and Corvallis also conducted trials at Pendleton and Moro, to evaluate varietal resistance, the biology of the pathogens and the infection process, seed treatments for chemical control, effects of planting depth, planting date, soil moisture, soil temperature, alternate hosts for the pathogens, and other potential management practices. Additionally, other tests at Pendleton also evaluated practices for controlling dwarf bunt, flag smut, oat smut and barley smut. In most of those experiments, the pathogens were inoculated into the soils or onto the seeds to enhance the uniformity of the results across replicates within each experiment. Scientists at the Pacific Northwest Smut Control Laboratory (USDA-ARS) at Pullman, in their publications and annual reports, always acknowledged Merrill Oveson, Bill Hall and Dr. Charles Rohde, at Pendleton and Moro, as key cooperators and contributors to smut control research.

Smut scientists at Pullman continued to conduct breeding and disease control research at many locations. They determined that treatment of seed with PCNB controlled smut from both soilborne and seedborne sources of inoculum. Improved control of seedborne spores by the mercurial fungicides, Panogen and PMA, were also demonstrated in non-smutty soils. A new seed treatment consisting of hexachlorobenzene (HCB) was introduced during 1954 and thiabendazole (TBZ) and carboxin (Vitavax) were registered in the 1960s. New seed treatments were rapidly adopted by growers throughout the Pacific Northwest.

In 1968, Dr. Roland Line became the leader of the USDA smut and rust research program at Pullman. Common bunt had been brought under control, but flag smut and dwarf bunt remained poorly-controlled. Drs. Line and Robert Metzger continued to examine races of most smut pathogens and methods for controlling the smut and bunt diseases in trials at Pendleton and Moro. Those trials were in collaborations with Matt Kolding and Dr. Rohde.

In 1976, Dr. Robert Powelson, from Corvallis, tested 31 fungicidal seed treatments in replicated trials at Pendleton and Moro. He inoculated soil with common bunt spores and found that wheat in the various treatments ranged from 0 to 41 percent smutted plants, compared to 36 to 42 percent in the non-treated controls, and none in the non-inoculated controls.

Common bunt was brought under very efficient and long-lasting control by the combination of seed treatment and genetic resistance. This dual control strategy prevented or greatly delayed further adaptation of the pathogen to overcome resistance genes in newly-released wheat varieties. But, throughout the 1990s and into the 2000s, Dr. Charles Rohde could always find and collect at least a few heads affected by common bunt at the Pendleton Station. His tactic was to make careful observations in wheat breeding trials that had been planted without seed treatment. The common bunt pathogens were obviously surviving in soil over long periods, even when the disease was not noticed during the many decades in which treated wheat seed has been planted.

In an analogous circumstance that occurred elsewhere, but has not been documented locally, common bunt has reportedly re-emerged as a severe disease in wheat that is grown under organic conditions where application of effective chemical fungicides are not allowed (Matanguihan et al., 2011). Organic wheat is a niche commodity that is becoming increasingly popular and more-widely produced in regions served by the Pendleton and Sherman Stations.

In 1995, Dr. Richard Smiley reviewed the status of smut disease control practices in Oregon and Washington. Control of common bunt had been very difficult before more effective fungicides were developed. Resistant varieties were quickly overcome by these rapidly-evolving pathogens. The combination of treating seeds of smut-resistant varieties with more efficient fungicides was totally effective but also allowed wheat breeders to shift their emphasis away from releasing smut-resistant varieties. The wheat breeding industry now releases many smut-susceptible varieties, which places near total reliance on the continued efficacy of fungicides for controlling smut diseases. Smiley and Patterson (1995) noted that 32 percent of winter wheat varieties recommended for production in Oregon and Washington during 1995 were susceptible to common bunt, and most were susceptible to dwarf bunt and flag smut. Six of eight varieties of soft white wheat released in Oregon were susceptible to common bunt and one of 10 varieties from Washington were susceptible. The authors concluded that this evolving circumstance creates a potential for selection or evolution of fungicide-resistant pathogens. Since there is now little or no testing of newly developed wheat varieties for their reaction to the smut pathogens, the industry is gambling on the continuing efficiency of fungicides for controlling common bunt.

Dwarf bunt

This disease exhibits symptoms like those of common bunt, except that the plants are considerably stunted. Dwarf bunt continued to be a problem even after common bunt was brought under control. Dwarf bunt occurred at higher elevations in eastern Oregon, including parts of Wasco, Union, Baker and Wallowa counties. Seed treatments such as carboxin (Vitavax) had provided minimal protection against dwarf bunt. Smiley conducted seed-treatment experiments in each of the above-named counties and found that the disease could be eliminated by treating seed with the experimental fungicide difenoconazole (Dividend). Results of Smiley's research made important contributions to the registration of that new fungicide. Dwarf bunt was brought to an abrupt halt as a yield-reducing disease when Dividend became registered for commercial use as a seed treatment in 1994 (Sitton et al., 1995).

Flag smut

The flag smut pathogen was first detected in the U.S. during 1919 (Malik and Mathre, 1997) and was detected in northcentral Oregon and southcentral Washington during 1940. Flag smut became considered as the most important disease of wheat in Wasco County during the late 1960s. During the late 1980s Dr. Roland Line provided support when Dr. Richard Smiley notified him that flag smut was reducing the yield of club wheat by about 50 percent in a wheat field southwest of Pendleton. These scientists determined that this was an isolated event caused by a grower who planted untreated seed of a susceptible variety during two successive crops in a wheat-fallow rotation. He planted self-saved seed and did not treat the seed with a smut-controlling fungicide. The pathogen had obviously survived in his field for decades even though the disease had not been noticed when he had planted treated wheat seed.

Smiley therefore conducted field trials and applied added inoculum of the pathogen to assure a uniform and severe disease occurrence. He found that the inoculum would not have been needed. More than half the plants in the non-inoculated control treatment succumbed to flag smut. The disease occurred on nearly all inoculated plants that were produced without the protection of a seed treatment. The standard carboxin treatment at that time (Vitavax) reduced the percentage of affected plants in inoculated soil by 50 percent, and the experimental fungicide difenoconazole (Dividend) completely eliminated flag smut. The question as to whether the flag smut pathogen had become partially resistant to carboxin after decades of planting carboxin-treated seed was never investigated further and remains an unanswered question.

Karnal bunt

The Karnal bunt pathogen was introduced into the Pacific Northwest during the 1990s. The field in which a wheat breeding trial had been conducted became contaminated and was quarantined. The disease has not been reported again in the Pacific Northwest. However, little was known about the potential for the pathogen to survive and become established if or when it was introduced again. Drs. Richard Smiley and Ronald Rickman, at Pendleton, used weather models to predict the potential risk of Karnal bunt if the pathogen were to be introduced to key wheat-producing regions of the Pacific Northwest. The weather was considered favorable for disease to develop in dryland wheat during one of every three years at one location in Oregon and one in Washington, and during every year where wheat is irrigated in each state (Smiley, 1997).

Stripe rust

The most important rust disease in Oregon has been stripe rust, which was first mentioned in the 1915 Sherman Station Annual Report. It was stated that, "*For the first time, grain rust* [stripe rust] *was present in abundance on the winter wheat*. … *The rust apparently did little damage, as the club varieties showing the highest percentage of infection gave the highest yields*."

Fred Schneiderhan was in charge of cereal investigations at the Sherman Station during 1916. He rated all entries in all cereal breeding and testing nurseries for stripe rust. He also made observations for stripe rust in fields throughout Sherman County, and in grasses along roadways and the railroad. His nurseries contained 713 entries in the fall-planted nursery and 313 entries in the spring-planted nursery. Schneiderhan found four varieties to be completely infected; "*The ground in proximity to* [these varieties] *was literally yellow with spores*. … *Even though the plants were very heavily infected they appeared to be developing normally in height, size, and length of heads*." However, he also stated that the occurrence of stripe rust in 1916 was far less severe than the epidemic in 1915, and that none of 130 Crimean wheats varieties (also known as Turkey wheats) became infected in 1916. Many other non-infected or only slightly-infected entries were also observed in plots planted side-by-side with entries that varied in infection levels from 40 to 75 percent. Overall levels of infection were higher in the spring-planted nursery than in the fall-planted nursery. Entries in the spring plantings varied from being 100 percent infected to no evidence of any infection. For the second year in a row, "*the most heavily infected varieties did not appear to suffer in growth or maturity but gave the highest yields*. … *Some of the India wheats were so heavily infected that the leaf surface was nearly covered with pustules, only narrow patches of green remaining, yet these varieties developed normal heads and seeds*."

During 1916, Schneiderhan also reported on the occurrence of stripe rust on wild grasses in the canyons and along roadways and the railroad. He identified the species that were infected and stated that the weed grasses needed to be studied as sources of inoculum for the rust occurring in wheat crops. He then compared weather data for 1915 and 1916 and found that the heavier epidemic in 1915 occurred when the spring growth began earlier than normal, plants became ranker than normal, and April temperatures were lower than normal and the precipitation was greater than normal. The winter of 1915-1916 was also unusually cold and had more alternations of freezing and thawing than the winter of 1914-1915, likely causing more death of the stripe rust fungus during the winter of 1915-1916.

In 1917, Schneiderhan planned to make stripe rust observations on an expanded set of nurseries. His fall- and spring-planted nurseries consisted of 902 and 400 entries, respectively. However, he moved to Washington, D.C. and that work was left to the Station Superintendent, David Stephens.

The Sherman Station participated in a national program to screen two susceptible wheat varieties for three species of wheat rust during 1919. The wheat was distributed by Kansas State Agricultural College. In response to an inquiry from Kansas, Stephens stated in a letter, dated May 28, 1919, that "*There is no stem or leaf rust on either one. In fact, we have not observed any stem or leaf rust on any of our wheats. We do not very often have either of these rusts. We have, however, this year quite a serious epidemic of stripe rust*." Stephens then reported the percentages of leaves rusted, which ranged from 5 to 100 percent.

The correspondence regarding rust diseases continued. In the 1948 Sherman Station Annual Report, there was an entry as follows: "*The long cool growing season this year favored the development of rust. The two predominating types were stripe and leaf rusts. Some stem rust was observed. This is an unusual occurrence in the dryland areas and it is not believed rust resistance is too important in a variety. However,* *certain varieties showed definitely more susceptibility than others. No physical damage* [from the rust] *was observed, however*." In 1963 the yields of wheat were very high due to excellent planting conditions which allowed fields to be planted early. "*But stripe rust occurred in epidemic proportions again in 1963. While Gaines showed superior mature plant resistance with little or no reduction in yield while, at the same time, fields of Omar were adversely affected by rust*."

As stated previously, in 1968, Dr. Roland Line became the leader of the USDA program at Pullman for controlling smuts and rusts of cereal crops. He developed a regional research program that collaborated closely with Dr. Charles Rohde, who screened varieties for resistance to stripe rust at Pendleton, Moro, and at 17 off-station locations. Rohde also modified the growth chamber facilities at Pendleton to switch the focus from studies of winter hardiness to studies of stripe rust. He sent spore samples from most of his studies to Dr. Line for identification of the races of the pathogen. Line tested some of that material at Pullman and also sent samples to the USDA Cereal Disease Laboratory (St. Paul, MN) for a more intensive testing of races. That collaborative process continued when transitions in leadership occurred at Pendleton and Pullman.

Senator Scott Duff in the greenhouse with Drs. Pamela Zwer and Richard Smiley

Dr. Pamela Zwer became the wheat breeder at Pendleton after Dr. Rohde retired in 1987. She became widely recognized for breeding wheat varieties with advanced levels of resistance to stripe rust (Zwer and Qualset, 1992 and 1994). A new greenhouse and potting shed were constructed at Pendleton to provide additional facilities for Zwer's research on stripe rust and Hessian fly. In 1997, Dr. Xianming Chen became the leader of the regional stripe rust research program. He had been a student of Dr. Line at Washington State University.

During 1985, Dr. Christopher Mundt became the plant disease epidemiologist at Oregon State University, at Corvallis. Mundt developed a program on the dispersal of stripe rust pathogens and the development of rust epidemics. Some of the field research by Mundt and his graduate students was located on the stations at Pendleton and Moro. Dr. Christina Hagerty, a former student of Mundt, is the current plant pathologist at the Pendleton Station. Her studies include evaluations of fungicides to control stripe rust.

Eyespot

Many growers in the Pacific Northwest call the eyespot disease by names such as foot rot, strawbreaker foot rot, Cercosporella foot rot or Pseudocercosporella foot rot. The first documented mention of its importance and a need for research was stated in a letter from Dave Stephens to Carleton Ball, Principal Agronomist, Cereal Crops and Diseases Branch, Bureau of Plant Industry, Washington, D.C. On June 30, 1928, Stephens stated "*I had visited the wheat section where foot rot was reported with our Pathologist, M. B. McKay, and Doctor Humphrey, of your Office. We actually saw 800 acres badly infected. Local reports indicated probably 1,000 to 1,200 acres in the district. Mr. McKay reported by telephone after he and Doctor Humphrey had been in* [Klickitat County] *Washington that the trouble is more serious on that side of the river, both as to intensity and acreage.*" Stephens also stated that bankers who provide loans to farmers had asked the Sherman Station to recommend what their farmers should do. Stephens therefore told

Ball that experiments in crop management and economic studies were needed to advise farmers until a solution to the disease could be found. Stephens requested that Ball send Mr. Hurley Fellows (USDA plant pathologist at Kansas State College, Manhattan, KS) "*to The Dalles to make a real investigation of the problem, including the life history of the disease along with temperature, moisture, altitude, and other factor relationships*." Stephens continued with statements that after such an initial visit, if warranted, Fellows could return later to conduct detailed research on the problem. Stephens then sent a telegram to Ball to re-enforce his commitment that Oregon "*will finance local expenses and subsistence Fellows during survey foot rot Wasco County provided there is possibility returning later for research on problem*."

Dr. Hurley Fellows made an almost immediate trip to the region and found that eyespot was prevalent in Wasco and Union counties in Oregon and in Klickitat and Spokane counties in Washington. It occurred to a lesser extent in other counties. Fellows took some affected plants back to Kansas for further evaluation. He sent a letter to Stephens stating "*The behavior of the diseased plants was unlike any foot rot we have seen. There is a possibility that we may have a mixed infection* …" Hurley and Stephens then collaborated to conduct experiments in Wasco and Union counties during 1928-1929. Their field trials evaluated varieties for resistance, effects of seven types of fertilizers, and effects of planting date, row spacing, seed drill design (deep furrow versus disk drill), and burning of stubble. After finding some disappointing results, Stephens notified bankers such as Ladru Barnum, of The First National Bank at The Dalles, "*I hope we will get some useful information, but it is my opinion that the problem will not be solved in a year*." Barnum replied that they will be happy to take this up with members of Congress to get additional funding from Washington, D.C. Stephens reported in 1930 that most wheat varieties were very susceptible to the disease and that none of the varieties were truly resistant. Nearly a century later, pathologists and wheat breeders in the Pacific Northwest and at many other locations in the world, continue to breed varieties for resistance to eyespot, and study the biology of two pathogens now known to cause the disease.

It was Dave Stephens who provided the coordination and stimulus for the investment that enabled Dr. Fellows' to conduct his research. Funds were provided by the experiment stations in Oregon and Washington, and by the Federal government. Nearly all research on the biology of the eyespot pathogens for the next three decades became centered at Washington State University. Little additional research on eyespot occurred until 1959, when Dr. Robert Powelson became a plant disease epidemiologist at Oregon State University. He developed a strong research program on methods to control the disease.

Soon after Powelson became employed in Oregon, eyespot (called foot rot at that time) was referenced in the 1963 Sherman Station Annual Report. Wheat yields in Sherman County were at an all-time high that year. Several fields yielded in excess of 70 bushels/acre and the county average was 39 bushels/acre. However, much of the increase in overall yield was due to favorable conditions in the low-yielding areas. Conditions were also favorable in the high-yielding areas but the farmers had planted much of that area to the new semi-dwarf variety Gaines. The majority of fields were planted early and suffered from serious occurrences of eyespot. Fields that were planted late were not seriously affected by the disease. That observation on the effect of planting date in commercial fields led to experiments that continue even to the present time.

Powelson developed his research in close collaboration with Dr. Charles Rohde. They quantified and refined the relationship between disease severity and the date of planting, and the identification of fungicides that controlled eyespot (Powelson and Rohde, 1972). They confirmed and quantified that the severity of eyespot became greatly diminished when winter wheat was planted during October or November, as compared to September. They determined that spraying plants with benomyl (Benlate) fungicide essentially stopped the progression of the disease, and that this became particularly effective when the fungicide was applied according to a risk-prediction guideline that had been developed by Powelson. The guideline was based on the percentage of seedling tillers having eyespot lesions during early spring, the variety of winter wheat, and the most likely weather scenario during the remainder of the spring. In 1978, Dr. Paul Koepsell, O.S.U. Extension Plant Pathologist, at Corvallis, announced to county agents and other interested parties that "*Benlate has been approved for use on wheat to control Cercosporella foot rot … in the eastern counties of Oregon.*" Benlate became the primary manner in which the disease was controlled for the next two decades.

During the mid-1980s, USDA wheat breeders and plant pathologists at Washington State University identified a winter wheat variety that was resistant to eyespot. They also identified the resistance gene that was expressed in the new variety. Madsen became registered for commercial production in 1989, and immediately caused a precipitous decline in eyespot's negative impact on the production of winter wheat. Other varieties with even greater resistance and better agronomic traits quickly followed. These events caused a rapid transition from a disease that was only controllable by managing the planting date and a fungicide application into a disease that was almost completely controlled by planting a resistant variety.

After Powelson retired in 1984, Dr. Christopher Mundt became the plant disease epidemiologist at Oregon State University. Almost immediately, Mundt began to screen varieties for resistance in field trials on the Pendleton Station. He and Dr. Richard Smiley also evaluated fungicides, a process that became particularly important when Benlate was removed from commerce during the 1990s. No other fungicide provided as efficient control of eyespot as had been provided by Benlate.

In the long-term experiments at the Pendleton Station (see Chapter 6), eyespot was most damaging to winter wheat during years with a wet fall and spring, and became greater as nitrogen fertilizer rates became higher. Rasmussen and Rohde (1988) and Smiley et al. (1996a) reported that eyespot was approximately equal in burned and unburned plots of the residue management experiment. The occurrence of this disease also diminished as the planting date was delayed. Smiley (2009c) reported that eyespot severity increased in proportion to the rate of accumulation of heat units (growing-degree days) following the planting date.

During the 2000s, molecular tests were developed in Australia to estimate the amount of DNA of soilborne cereal pathogens in soils. Smiley applied that testing protocol to the long-term experiments at the Pendleton Station (see Chapter 6) and found that DNA quantities for the eyespot pathogens decreased precipitously each year following a crop of winter wheat in a 3-year rotation of winter wheat, spring wheat and fallow (Smiley et al., 2016). The concentration of DNA did not differ where stubble was either burned or incorporated. The eyespot pathogens were also detected in the perennial pasture but not where winter wheat, spring wheat or spring barley were produced annually. These findings led Smiley et al. to suggest a need for studies to determine if a natural biological suppression of the eyespot pathogens is occurring under certain crop management scenarios.

Cephalosporium Stripe

Cephalosporium stripe is a vascular wilt disease. The pathogen penetrates the roots and invades the xylem vessels which conduct water from roots to the foliage. The pathogen clogs the vessels and produces a toxin that, acting together, causes yellow stripes to occur in leaves. The plants become stunted and grain yield and quality are each greatly reduced. Some varieties are more heavily affected than others, but no genes for resistance are known and pesticide applications have been of no value. The focus has therefore been on cultural management practices and selection of the least susceptible varieties. Most research on the biology and control of Cephalosporium stripe has been conducted at Washington State University.

Studies at the Pendleton Station have focused on screening fungicide seed treatments and effects of variety selection and date of planting. Screening of seed treatments failed to identify any products that could suppress the disease. However, the occurrence of Cephalosporium stripe was greatly reduced when the date of planting was delayed (Smiley, 2009c). Screenings of varieties at the Pendleton Station and at nearby farms during the 1990s confirmed what was already known from the comprehensive studies at Washington State University. Most notably, Stephens winter wheat, which was the most commonly planted variety in Oregon, was exceedingly susceptible and left large amounts of fungal inoculum in the soil. Stephens dominated the plantings in Oregon for nearly three decades. Outbreaks of Cephalosporium stripe diminished soon after Stephens became replaced by varieties that were less susceptible to the disease. More recently, and over many years, Dr. Christopher Mundt has been assaying advanced wheat breeding lines in experiments at the Pendleton Station. His trials are performed by inoculating soil with the pathogen and planting wheat quite early. While results do not appear to have been published, it is clear that germplasm with excellent resistance is being advanced toward release as commercial varieties.

Chloride-deficient leaf spot

A leaf spot that resembles leaf spots caused by fungal pathogens occurs periodically on wheat in the Pacific Northwest. It had been observed for at least six decades, and was called 'no-name disease.' During the late 1980s and early 1990s, the leaf spot became particularly well developed on Stephens winter wheat, which was the most prevalent wheat variety planted in the region at that time. The no-name disease sometimes killed as much as 60 percent of the flag leaf tissue. During the 1980s, large acreages of winter wheat were being sprayed with expensive fungicides because the disease resembled leaf spots caused by fungal pathogens.

Dr. Richard Smiley and colleagues attempted to determine the cause of the no-name disease, and to determine whether applications of fungicides could reduce disease severity and improve grain yield, and to quantify the reductions of grain yield and quality. After extensive biological and chemical testing, Smiley et al. (1993a) concluded that "*… we present no evidence that a microbial agent incites this disease.*" They therefore proposed a preferred default name of 'physiologic leaf spot.' They also documented that the disease could reduce yields by up to 10 percent.

Smiley et al. (1993b) also found that fungicide applications had no effect on disease severity, disease occurrence or grain yield. However, the severity of leaf spot differed among wheat varieties and crop rotations, and became less severe as winter wheat planting dates were delayed and nitrogen application rates were increased. The disease was unaffected by management of wheat stubble (burning versus incorporation) or application of common micronutrients. Most importantly, Smiley et al. determined that physiologic leaf spot severity and reduced grain yield could be largely overcome by an application of calcium chloride. They discussed potential implications of that finding with regard to the physiology of plant growth, and pointed out that it appeared possible that chloride could be deficient for wheat production under some circumstances.

Those reports captured the immediate attention of the McGregor Company's Research Division, at Colfax, WA. During the following decade the McGregor Company conducted dozens of experiments with chloride fertilizers across the wheat-producing regions of all three Pacific Northwest states. They documented that application of chloride improved wheat yields in some locations, and that this occurred even when symptoms of physiologic leaf spot did not occur. Other fertilizer supply companies took note of those findings and many growers now apply chloride as part of their standard fertilizer package. More recently, the disease was renamed 'chloride-deficient leaf spot' (Smiley, 2010b).

Virus Diseases

Diseases caused by virus-like entities were detected within the first decade of research at the Sherman Station. David Stephens sent a sample of diseased potato to Oregon State Agricultural College for diagnostic support. On June 29, 1917, plant pathologist M. B. McKay penned a response to Stephens that stated "*The plant appeared to be affected by the non-parasitic inherited weakness which we call curly dwarf. … the plant is often dwarfed and the leaves are curled and crinkled … the veins on the underneath side of the leaves are black and dead. Curly dwarf is … a disturbance of the vascular system of the plant, the cause of which is unknown*." Today, this malady would be diagnosed as being caused by potato spindle tuber viroid, which is an infectious single-stranded RNA molecule with no protein coat. Stephens requested that one of the entomologists travel to Moro to evaluate the potato crop for the three problems known to be occurring on potato; curly dwarf, *Rhizoctonia* and wireworm. The curly dwarf problem was taking a severe toll on some of the potato varieties even though the Station staff had carefully culled all visually affected potato seed before the 'healthy' seed was planted. The entomologists replied that they would be happy to do so if Stephens paid all their expenses for the trip.

The 1958 Pendleton Station Annual Report (see Appendix 6) provided what is the first mention of barley yellow dwarf. Merrill Oveson and staff stated "*this was the first ever year for an epidemic outbreak of barley yellow dwarf. The virus was most pronounced on barley but also occurred on some oats*." Occurrences of barley yellow dwarf and wheat streak mosaic occur periodically at the dryland stations but the frequency and severity have been too low to conduct field research on these virus-caused diseases. Moreover, local research was considered unnecessary because these diseases have been studied extensively at Washington State University.

Patches of yellow, stunted wheat caused by wheat soilborne mosaic virus

Wheat soilborne mosaic was discovered in irrigated wheat in the Columbia Basin during the 2007. The virus is vectored into wheat by a fungus-like parasite that lives in soil. During the spring of 2008 the disease caused sometimes severe patches of yellowed, stunted non-irrigated winter wheat near Walla Walla. The malady was first observed by agri-business agronomists and farmers, who then reported it to Dr. Smiley at the Pendleton Station. Since most of the affected fields were in Washington, Smiley arranged an on-site visit of farmers, agribusiness, county extension services, and plant pathologists from Washington State University. Dr. Timothy Murray, from Washington State University, conducted further samplings to confirm the cause of the disease (Murray et al. 2009) and determine the amount of yield loss caused by wheat soilborne mosaic in non-irrigated fields. In 2017, Dr. Christina Hagerty initiated additional studies to quantify crop loss, geographic distribution, and varietal resistance. Hagerty's program also produced a diagnostic guide to assist growers in identifying and dealing with the problem (Kroese et al., 2018).

Symptoms Mostly in Roots and Crowns

Currently, the most important diseases of wheat and barley in dryland regions of eastern Oregon are caused by soilborne pathogens that infect roots or crowns. These diseases reduce grain yield and grain test weight by restricting uptake of water and plant nutrients, thereby inducing premature drought and nutrient deficiency stresses on plants. Some of these diseases do not produce symptoms that are readily detectable in the foliar canopy, and are therefore not apparent until the crop is nearing maturity.

Root and crown diseases are not yet controllable with genetic resistance or by application of a pesticide. Suppression of these diseases is still mostly reliant on changing the way the crop is managed, such as altering the planting date, seed depth, tillage intensity, managing stubble, rotating types of crops, or other such practices. Research at the dryland stations during recent decades has therefore been focused on diseases of wheat roots, crowns and lower stems.

The importance of root diseases cannot be understated. Their potential impact can be deduced from plant growth models developed by Drs. Betty Klepper and Ron Rickman (see Chapter 18). Klepper and Rickman's research showed that the theoretical development and growth of roots consistently over-estimated by a factor of two the numbers of root branches and root axes that were actually measured. Therefore, to fit the models to the measured data for roots, Rickman and Klepper divided the theoretical values by a factor of two. They therefore published models that present a strong relationship between the theoretical maximum and the actual measurements. That reduction of theoretically possible root numbers and root growth, by 50 percent, presented a very important implication for the importance of root diseases in wheat-based farming systems in the dryland region. These 'root-nibbling' diseases are very difficult to detect and are even more difficult to quantify and control.

Pythium diseases

Many species of *Pythium* cause diseases such as seed rot, seeding damping-off, and root rot. In a date-of-seeding trial with winter wheat at the Sherman Station during 1913, no seedlings emerged from the earliest planting date, which was September 12. When wheat was planted on October 25, shortly after rains occurred on October 21, cold weather and snow occurred before any seedlings emerged. A thaw in January melted the snow and it was noted that all of the winter cereals had emerged and had fair stands. Cold weather returned and freezing weather during February left a sheet of ice over many of the plots for a period of 10 days. In the variety testing nurseries, planted during early October 1913, most of the winter wheat varieties failed to emerge and the winter barleys and winter oats did not emerge at all. Only eight winter wheat entries grew to maturation. The 1913 Sherman Station Annual Report stated "*The seed evidently rotted before sufficient rain came to start germination*." Current knowledge suggests that these were classic descriptions of Pythium seed rot, seedling damping-off, and root rot.

During the 1980s and 1990s, comprehensive studies by Dr. R. James Cook (USDA, Pullman, WA) demonstrated that *Pythium* diseases were very difficult to identify but were widespread and were caused by numerous species of *Pythium*. He reported that these diseases were especially damaging when growers planted old wheat seed, or in situations where fresh but untreated wheat seed was planted into cold soil.

The importance of *Pythium* diseases became clear during 1994. Prior to that time, most seed planted in the Pacific Northwest was treated with fungicides. The common treatments contained thiram plus a fungicide such as carboxin to control smut diseases. Thiram was an irritant and was particularly disagreeable to people who handled it. Carboxin was an old product that was being replaced by difenoconazole (Dividend). Essentially all testing of Dividend prior to its registration had been conducted on wheat planted during mid-September to mid-October. Release of Dividend was widely anticipated by wheat growers but it didn't receive full registration until late fall. Coincidentally, the summer fallow in 1994 was very dry because there had been no significant rainfall from summer through late October. Most growers had to delay winter wheat plantings. They therefore purchased seed treated with Dividend and planted in late October. The weather turned wet and cold almost immediately after most of the fields had been planted. It took many weeks for seedlings to emerge, and it was quickly determined that massive amounts of seed rot and seedling damping-off were occurring in commercial fields. Dr. Richard Smiley examined and sampled a commercial experiment that showed immense differences in plant establishment for plots treated with Dividend alone or with Dividend plus metalaxyl (Apron), a fungicide that is toxic to species of *Pythium*. Smiley replicated those treatments in greenhouse tests and showed that thiram, which had been used prior to 1994, had unknowingly been suppressing *Pythium*, and that the companion products of Dividend plus Apron were each necessary when winter wheat was planted into cold wet soil (Smiley et al., 1996b). The manufacturer immediately changed the Dividend label to require that Dividend and Apron be applied together on all treated wheat seed sold in the Pacific Northwest. Although formulations and products have changed over the past two decades, the principle continues to be followed that multiple fungicides, including a product that suppresses growth of *Pythium*, be applied to wheat seed planted in this region.

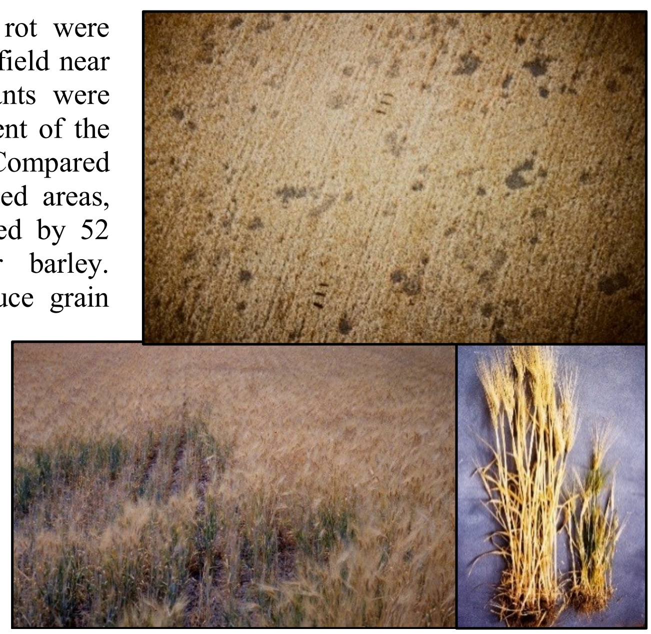
Rhizoctonia diseases

The first mention of diseases caused by *Rhizoctonia* occurred in the 1917 Sherman Station Annual Report. "*Because of the severity of disease in the potato crop of 1916, all new seed lots were acquired for planting during 1917, and all of the seed pieces were treated for three hours with a solution of corrosive sublimate. Nevertheless, soon after emergence the vines began to show indications of disease. Professors from Washington State Experiment Station and the Oregon Agricultural College each found the Rhizoctonia fungus to be present.*" The disease was again noted during 1937, when potato yields were low because of the disease. The authors of the report noted that "*The source of the seed and its freedom from disease are of more importance under the dry conditions prevailing at Moro than is the variety*."

Rhizoctonia diseases of field crops in Oregon were not mentioned again until Pumphrey et al. (1987) reported the occurrence of Rhizoctonia root rot of irrigated winter wheat at the Hermiston Station. The disease caused patches of depressed growth ('bare patches') in which the yields were depressed by more than 50 percent. The bare patches were much more prevalent in conservation tillage systems than in moldboard-plow based tillage systems. Disease severity was inversely correlated with the amount of soil disturbance during seedbed tillage, but was unaffected by the rate or timing of nitrogen applied. Dr. Richard Smiley observed similar patches of stunted wheat and barley in many dryland fields throughout the region. Smiley invited Drs. R. J. Cook (USDA, Pullman, WA) and Akira Ogoshi (Hokkaido University, Sapporo, Japan) to sample affected fields and identify the *Rhizoctonia* species and sub-groups that were associated with those patches.

Yield reductions by Rhizoctonia root rot were estimated in one wheat field and one barley field near Helix during 1987. Patches of stunted plants were measured and found to represent eight percent of the wheat field and 17 percent of the barley field. Compared to yields for crops outside the patch-affected areas, grain yields inside the patches were reduced by 52 percent for wheat and 54 percent for barley. Rhizoctonia root rot was estimated to reduce grain yields in those fields by four percent for wheat and eight percent for barley (Smiley et al., 1989).

Smiley also evaluated fungicide treatments. He selected fungicides that were shown to be highly toxic to the pathogens in their laboratory tests. He then coated fertilizer granules with the best of the fungicides and banded the coated granules with the wheat seed, below the wheat seed, or between seed rows. These treatments were applied in both conventional (chisel plow and disk) and no-tillage systems. He also examined fungicide seed treatments. None of the fungicide treatments provided consistent and measurable increases in grain yield. However, application of the starter fertilizer with the wheat seed caused Rhizoctonia root rot be become more severe in the no-till but not in the conventional tillage system (Smiley et al., 1990, 1991).



Rhizoctonia root rot, with patches of stunted barley plants near Helix; the aerial photograph contains two 10-foot grids painted at 5-foot intervals onto barley heads to reveal scale

Smiley and Wilkins (1992) noted that the widespread and rapid adoption of sulfonylurea-type herbicides (chlorsulfuron; Glean) to control weeds in fallow of conservation tillage systems coincided with the period in which Rhizoctonia root rot became much more prevalent on winter wheat and spring barley in conservation tillage systems. The scientists conducted field studies to determine whether they could demonstrate a cause-and-effect relationship between that new class of herbicide and the increasing importance of Rhizoctonia root rot. They first collected undisturbed cores of soil from fields that were treated or not treated with the herbicide. They grew wheat in those cores in the greenhouse. Seedlings in soils treated with Glean had more severe root rot and reduced growth than seedlings growing in untreated soil. Smiley and Wilkins then conducted field experiments for two years on a commercial field near Helix. They again demonstrated that the disease became worse in soils treated with Glean. However, under field conditions, they observed an initial seedling stunting and greater root rot, but then the plants recovered as they matured. The scientists found that yield was reduced by herbicide application in only one of eight experiments. They concluded that the herbicide definitely predisposed the plant to greater infection by the pathogen but the process did not necessarily result in a reduction of wheat yield.

Another herbicide-related phenomenon became evident as the use of glyphosate (Roundup) and no-till agriculture simultaneously became increasing popular during the 1980s. At the same time, 3-year rotations of winter wheat, spring barley, and chemical fallow were being evaluated as conservation production systems. The compression of the timing for field work during the spring, during periods between rainfalls, caused it to become a typical practice to apply the glyphosate to kill volunteer wheat and winter annual grass weeds shortly before planting the spring barley. Rhizoctonia root rot became very common and severe in spring barley planted into conservation tillage systems throughout the region. Australian scientists reported that the timing between application of a kill-down herbicide and planting the wheat or barley seed had an immense influence on the severity of Rhizoctonia root rot in that country. Smiley et al. (1992) evaluated the interval between spraying volunteer and planting spring barley in Oregon and Washington. They confirmed that root rot became much more severe as the time interval was reduced. The least disease amount of Rhizoctonia root rot occurred when weeds and volunteer were killed in the fall and were not allowed to grow during the winter. If the plants were allowed to overwinter, the root rot was much more severe when the time interval between spraying and planting was two or three days compared to three weeks. The several-day interval was the most commonly used system in the region, and Smiley et al. (1992) showed that barley yields could be reduced as much as 50 percent by Rhizoctonia root rot compared to expanding the timing interval to three or more weeks. The authors hypothesized that the fungus built up energy on the roots of dying weeds and volunteer wheat that had been recently sprayed with glyphosate, and then quickly moved from the dying plants to the roots of newly emerging barley seedlings. At greater time intervals between spraying and planting, the pathogen vigor diminished in the absence of living roots, accounting for the reduction of disease as the interval was increased. Also, the authors demonstrated that the effect of the short timing interval could be nullified if the soil was lightly tilled prior to planting. The authors hypothesized that the web of fungal mycelium in shallow soil became disrupted and less effective for infecting plants when the soil surface was lightly tilled before or as the barley was planted. Smiley et al. (1992) described this phenomenon as the 'green bridge' in reference to the bridging effect that carried the pathogen from dead or living roots of weeds and volunteer cereals to the next set of roots of the newly-planted crop. The green bridge concept became widely acknowledged and growers quickly adopted the practice of killing vegetation as far as possible in advance of planting their spring crops. This concept is now considered the single most important way in which damage from Rhizoctonia root rot can be minimized.

Smiley and Wilkins (1993) reported studies on the effects of tillage systems and weed control practices on Rhizoctonia root rot of spring and winter barley at two very low rainfall locations near Nolin and Helix, in Umatilla County. They found that loss of soil water from tillage during the spring was more important than the tillage system for producing the highest grain yields. The root rot was always more severe in spring barley than winter barley, and in no-till systems than in cultivated tillage systems. However, grain yields did not correlate with the severity of Rhizoctonia root rot because the soil water factor was of greater importance. Barley yields at both locations improved as the number of years of annual spring barley production increased from the first year to the fourth year. In a concurrent study, Lucas et al. (1993) demonstrated in a greenhouse at Pendleton that Rhizoctonia root rot declined with successive plantings of wheat into undisturbed cores of soil collected from an infested field. If the soil was mixed, to simulate a tillage operation, the severity of root rot did not decline with successive wheat plantings. This was cited as evidence for the occurrence of a biologically mediated disease decline phenomenon in soils planted annually to a susceptible crop.

Drs. Pamela Zwer and Richard Smiley screened 216 lines of winter wheat to determine their susceptibility to damage by Rhizoctonia root rot. These field studies were conducted for two years in large experiments at the Sherman and Pendleton stations. Paired rows of each wheat entry were planted across four replicates of 15-foot-wide strips that had either been inoculated with *Rhizoctonia* or left in the native state, without added inoculum. The scientists determined that five of 216 lines yielded nearly as well in inoculated soil as in the control plots. These results were particularly spectacular at the Sherman Station. However, it was also noted that wheat lines varied greatly in tests conducted at different locations and during different years.

The biology of *Rhizoctonia* pathogens in soil is complex. Fields in the region contain at least three species of *Rhizoctonia* and two of those species contain many biotypes that provide genetic diversity within those species. Several of the pathogens cause seedling damping-off and other species do not cause that symptom. One of the major pathogen types causes a rotting of the roots, leading to a characteristic 'spear tip' symptom that can be diagnosed by washing and inspecting the root system. Other *Rhizoctonia* types do not cause that symptom. One *Rhizoctonia* species causes a stem lesion and rot similar but less severe than caused by the eyespot pathogens. Some of the pathogens cause the most damage to canola whereas others cause the most damage to wheat and barley. Research on the biology of these pathogens in the Pacific Northwest has been conducted mostly at Washington State University. Only a few such studies were performed at Pendleton. The study of a disease decline phenomenon (Lucas et al. 1993) was described earlier. Smiley and Uddin (1993) compared the temperatures most favorable for activity of the two most common *Rhizoctonia* species that affect dryland cereal crops. Although they found that the two species were each commonly detected in soil, in greenhouse and field tests they determined that the pathogen *Rhizoctonia solani* AG-8 was the most important on winter wheat and spring barley because the soil temperature during the period in which seedlings become infected is highly favorable for growth of that pathogen and much less favorable for growth and infection by *Rhizoctonia oryzae*.

Rhizoctonia root rot was among the diseases monitored in the long-term crop residue experiment at the Pendleton Station (see Chapter 6). Smiley et al. (1996) reported that the disease was much more prevalent in a cultivated winter wheat-fallow rotation than in plots that were cropped annually to winter wheat in rotation with spring pea, or continuously as annual winter wheat. They also demonstrated an inverse relationship between the mass of beneficial microbes and the occurrence and severity of Rhizoctonia root rot, indicating a healthy level of competition among beneficial and pathogenic organisms in soils with the highest levels of organic matter. Within the winter wheat-fallow rotations, Smiley et al. (1996a) found that Rhizoctonia root rot was more severe in stubble mulch tillage systems (sweep or disk) than with inversion tillage by moldboard plow. This was consistent with the knowledge that this disease is generally more severe in management systems that retain the highest amount of cereal residue at or near the soil surface. However, when Smiley et al. (2016) quantified the amount of *Rhizoctonia* inoculum in soil, they found no relationship between the density of the pathogen and the severity root disease reported several decades earlier. Similar results were obtained when diseases were monitored in a long-term crop rotation at the Sherman Station (see Chapter 12). These findings supported the knowledge that the presence of the pathogen is only one component of the disease triangle; diseases occur when there is an alignment of the pathogen, the environment and a susceptible host. In these cases, the soil environment was exerting a strong influence on the ability of the *Rhizoctonia* pathogen to cause root disease on susceptible plants. Date-of-planting studies at the Pendleton Station suggested that neither rainfall nor temperature has a strong influence on the severity of Rhizoctonia root rot (Smiley, 2009c). The influence of other microorganisms appears to be a dominant environmental factor affecting the survival and infective potential for *R. solani* AG-8.

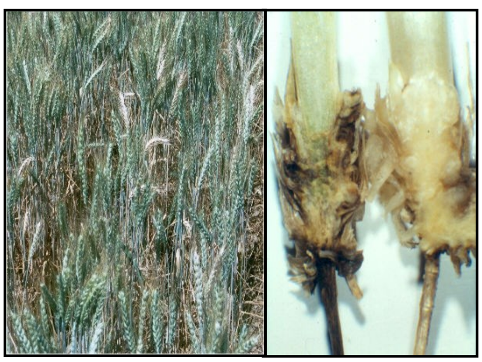
A 12-year crop and tillage management experiment near Ralston, in Adams County, Washington, was described in Chapter 12. In that experiment, Rhizoctonia root rot became the limiting constraint for producing barley in the crop rotations at that location. An image of extensive patches caused by this disease in that experiment is shown in Chapter 12. Because of this root rot, barley was eliminated from the experimental variables after the first four years of testing.

Smiley's research on Rhizoctonia root rot at Pendleton became the basis for several doctoral dissertations at Washington State University. Smiley served on the oversight committees for those dissertations. Most notably, Smith et al. (2003a, 2003b) repeated and refined the concept of the green bridge and also found evidence that genes for resistance to Rhizoctonia root rot were present in some landrace cereals. They proposed that it would be worthwhile to initiate a breeding program to transfer that resistance into agronomically improved wheat varieties for use in the Pacific Northwest. That has now been partially accomplished by scientists at Pullman, WA. In another dissertation, one of Smiley's former research assistants, using a genetic cross she initially made in her work at the Pendleton Station, developed a wheat mapping population ('LouAu') to identify genetic resistance to root-lesion nematodes (Thompson et al., 2015). The mapping population consisted of progeny between 'Louise,' a parent of Pacific Northwest origin, and a landrace wheat line (AUS28451) carrying resistance to the nematodes. The mapping population was then also found to possess partial resistance to *Fusarium culmorum* and *Rhizoctonia solani* AG-8, as well as resistance to two species of root-lesion nematode (Thompson et al. 2017). That mapping population is useful in breeding programs aiming to incorporate resistance to multiple soil-borne pathogens into other wheat varieties.

Fusarium crown rot

In 1919, most oat varieties in a screening test at the Sherman Station were killed by a disease that caused brown rot of crowns and a drying of foliage. The plants were evaluated by an Oregon Agricultural College pathologist but no positive identification of the pathogen could be determined. The disease occurred on oats again during 1921 but the cause of the disease still had not been identified. The next report of this malady occurred in 1934, when it was stated that oats were a failure due to an unidentified disease of the roots that was much aggravated by the drought. The roots rotted, the leaves turned a rusty red color, and the plants failed to develop properly. The late-maturing varieties were affected more than the early-maturing varieties. Dr. Roderick Sprague, who had moved from Oregon State College to Washington State College, collected samples and identified the pathogen as *Fusarium culmorum*.

In 1937, the oat variety 'Carleton' was specifically touted because it was less susceptible to Fusarium crown rot (called Fusarium foot rot at that time) "*which quite often attacks oats in this region*." The 1938 Sherman Station Annual Report indicated that "*The previously dominant variety of oats in the County ('Markton') is changing to Carleton because the latter is a little earlier in maturation and a bit higher in yield because it is less susceptible to attack by Fusarium culmorum*."



Fusarium foot rot also caused damage to the Turkey wheats during 1944 but caused less damage to the club wheats. Today, it can be surmised that these reports were the first observations of Fusarium crown rot (also called dryland foot rot) in wheat in Sherman County. The disease continues to be exceptionally important throughout the lower-rainfall regions.

During the 1950s, major increases in the importance of Fusarium crown rot coincided with the planting of higher yielding varieties, an increase in the rate of fertilizer applied, an emphasis on the practice of stubble-mulch ('trashy') fallow to control soil erosion, and the practice of planting winter wheat as early as possible to minimize soil erosion. Extensive research was conducted on Fusarium crown rot in Washington by Dr. R. James Cook from the 1960s until the 1990s. Cook and colleagues, which included Dr. Richard Smiley, produced a great many technical papers to report new understandings of the biology and control of the pathogens and the disease. It is a testament to the complexity and intransigence of Fusarium crown rot that control measures are still incomplete and do not include genetic resistance or chemical controls.

No specific research on Fusarium crown rot was performed in Oregon until Dr. Smiley became employed at the Pendleton and Sherman Stations in 1985. During the next three decades, Smiley conducted at least one hundred experiments to document the amount of crop loss associated with the disease, the identity and regional and genetic variability among pathogens, comparative virulence of various isolates of *Fusarium*, and potential control practices including chemicals, cultural management (especially date of planting, crop rotations, and tillage systems), and resistance or tolerance of wheat and barley varieties. Smiley's research group also crossed locally-adapted wheat varieties with imported wheat lines that were known to carry resistance to the same pathogens in other countries.

Smiley et al. (2005b) quantified the amount of yield loss caused by the disease in 13 winter wheat fields during 1994 and 1995. They measured yield components on tillers collected from commercial fields, and documented a yield loss of 35 percent in one field and a 13-field average of 9.5 percent yield loss during 1994. The greatest damage occurred during the driest year but there was also a substantial yield loss during a wet year, even though above ground symptoms did not occur when infections were of only moderate intensity during the wet year. Moreover, they also determined that Fusarium crown rot caused an increase in the grain protein content, which is opposite the industry objective of producing soft white winter wheat destined for low-protein end uses. The disease also reduced the test weight of wheat kernels, causing the grain to be downgraded to less-than-optimal market quality, resulting in lower prices for the grain produced. Severely affected grain was rated as marketable only for low-value livestock feed. Additionally, the disease reduced the tiller height and straw yield, which are both contrary to the objectives of Federal soil conservation programs. From that research, Smiley et al. concluded that "*Damage for crown rot in the Pacific Northwest is more widespread and damaging than previously recognized*."

Smiley and Patterson (1996) then conducted a 2-year survey to determine the identity and geographic distribution of pathogens associated with Fusarium crown rot in 288 non-irrigated fields in 10 Oregon counties and seven Washington counties. From more than 5,000 wheat crowns, they isolated and identified 25 different *Fusarium* species and two potential pathogens that cause similar symptoms on wheat; the common root rot pathogen and the pink snow mold pathogen. Five of those fungi were already recognized as pathogens of wheat. Among them, the most commonly isolated and geographically widespread species was *Fusarium pseudograminearum*, which was isolated at twice as many locations as the other crown rot species, *F. culmorum*. That research revealed that these fungal species were exceedingly responsive to different seasonal weather conditions, to the extent that a species that was the dominant species in a field one year could be less dominant than another species in that same field the next year.

The five dominant species detected in the survey were then screened to determine their pathogenicity to wheat in greenhouse tests and in fields at Moro and Pendleton (Smiley et al. 2005a). All five species reduced seedling growth but only two species reduced grain yield under field conditions; *F. pseudograminearum* and *F. culmorum*. That research also revealed a very high level of variability in pathogenic potential among isolates within the same species. For instance, *F. pseudograminearum* isolates from different fields and locations varied from pathogenicity ratings of 1.6 (almost not pathogenic) to 7.0 (plant death by rotting the seed or damping-off before seedling emergence). That research also provided an additional benefit that is now widely used in similar studies throughout the world. It involved an automated way in which to place known quantities of *Fusarium*-infested inoculum above the seed in a manner which forced the plant coleoptile to emerge through the zone of infested soil, closely simulating the process for fungal invasion of the plant under natural conditions in the field. The *Fusarium* pathogen was grown in the laboratory on previously sterilized millet seeds. The colonized millet seeds were then dried. When field experiments were being established, the colonized millet seed was placed into a fertilizer distributor mounted on the seed drill. The fertilizer box was calibrated to dispense known quantities of millet seed into each drill row, in a manner that placed it an inch or so above the wheat seed. Wheat could be planted in side-by-side drill rows either while placing pathogen inoculum into the soil, or by not doing so simply by shutting off the drive gear which operated the fertilizer box. Many comparative field studies with individual rows being either inoculated with the pathogen, or not inoculated, could be installed quickly and easily (Smiley, 2019). This automated, on-the-go, system for conducting these experiments precisely and rapidly became adopted internationally.

Since these fungi are very difficult to identify quickly and in large numbers, Smiley's laboratory at Pendleton, in 1998, became equipped with molecular diagnostic equipment to identify fungal isolates based on their DNA profiles. The use of that technology immensely increased the scientist's confidence that identification of these fungi was accurate. In more recent evaluations of fungal DNA isolated from long-term experiments at Moro and Pendleton, it was learned that cropping systems exerted an influence over which crown rot species might become dominant. At both locations, winter wheat selected for a dominance of *F. pseudograminearum* and spring wheat and spring barley selected for a dominance of *F. culmorum* (Smiley et al. 2013, 2016).

In a survey of crown rot in the long-term tillage × fertility experiment at Pendleton (see Chapter 6), crown rot was found to increase as the rate of nitrogen was increased and as the amount of wheat residue on the soil surface increased (Smiley et al., 1996a). The disease was far worse at high rates of nitrogen application under sweep tillage than at low rates of nitrogen under moldboard plow tillage. Since that experiment had continued since 1940, it also became possible to examine relationships between crown rot and soil chemical properties. Interestingly, it was revealed that the occurrence of crown rot increased in proportion to an increase in organic carbon and organic nitrogen, and with a decline in soil pH. Although these relationships could not be evaluated for cause and effect, they did suggest that crown rot was likely to become increasingly important as the adoption of conservation tillage practices become more widespread in the region.

Many cultural management practices were examined in an effort to reduce the severity of Fusarium crown rot. It was already stated that higher rates of applied nitrogen and higher amounts of wheat residue on the surface were associated with increasing severity of crown rot. Many screenings of seed treatment fungicides failed to identify any means for reducing damage by applying chemicals. Smiley (2009) demonstrated again that a delay in the planting date could have profound benefits with regard to reducing the occurrence and severity of crown rot. During three of the four years of that test, the percentage of plants that exhibited symptoms of crown rot exceeded 50 percent for plantings made during September, and from zero to 10 percent of plants that were planted in October. However, it was also determined that yield reduction was more highly correlated with combinations of diseases rather than a single disease in three of the five tests reported.

Many dozens of field trials were evaluated to determine if some varieties were more resistant than others. About half of those tests were conducted by wheat breeders. It was observed that responses of individual varieties to crown rot varied greatly from location to location and from season to season, likely due to variability in the pathogen species and isolate population, and in the weather. Smiley and Yan (2009) quantified that variability and concluded that as few as 24 comparisons (a combination of locations, years and replicates) could be used to confidently (95 percent) describe the crown rot tolerance of spring wheat varieties but that about 95 comparisons would be required to achieve that high level of confidence with winter wheat varieties. For winter wheat, 95 comparisons would require many replicated tests over many years which, because of the ever-changing composition of wheat breeding nurseries, would generally eliminate the possibility for generating confident and accurate recommendations for growers.

Smiley imported wheat varieties that spanned a spectrum of responses to crown rot in Australia, and were commonly used in that country as comparative standards for rating the responses of other varieties and breeding lines. Those lines performed that purpose just as well in field tests in Oregon as they did in Australia (Smiley and Yan, 2009). Wheat lines from the International Winter Wheat Improvement Program were also imported from CIMMYT and placed into wheat nurseries in Oregon. Some of the CIMMYT lines with purported resistance to Fusarium crown rot did not deliver that expectation when tested at the Pendleton and Sherman Stations. They were as variable in response as the Pacific Northwest selections that had already been tested. Smiley's program therefore crossed nine of the best local wheat varieties with three of the imported Australian varieties that showed the greatest level of resistance to crown rot. One of the three crossing parents was noted in Australia as containing adult-plant resistance and two were noted as containing seedling resistance to Fusarium crown rot. Smiley retired before advancing those crosses into further testing. Upon retirement, he offered numerous mapping populations and imported seed lots for distribution to wheat breeders in the public- and private-sectors. Breeders in Washington, Idaho and Montana expressed strong interest in those resources, and it was distributed to them in 2015.

Results of Smiley's research on Fusarium crown rot formed the basis for two doctoral dissertations at Washington State University, for which Smiley served on the oversight committees. Smiley served on those dissertation committees and provided samples of the pathogens in Oregon, and assistance with the student's access to field sites for sampling in Oregon. Most notably, Poole et al. (2014) revisited and refined information regarding climatic and geographic variables that influence the distribution of *Fusarium* species. They too found that the species respond differently to year-to-year differences in the weather. Poole et al. (2012) also identified the locations of *Fusarium* resistance genes on chromosomes of wheat, and refined the assay methods for use in greenhouse and field experiments with these pathogens. In another dissertation, one of Smiley's former research assistants, using a genetic cross she initially made in her work at the Pendleton Station, developed a wheat mapping population 'LouAu' to identify genetic resistance to root-lesion nematodes (Thompson et al., 2015). The mapping population was then found to possess partial resistance to Fusarium crown rot, Rhizoctonia root rot and root-lesion nematode (Thompson et al. 2017). The mapping population is being used to incorporate resistances to these soil-borne pathogens into other wheat varieties. Breeding wheat for resistance to Fusarium crown rot is now one of the research funding priorities of the Washington Grains Commission.

In another distant, but related, study in which Smiley participated, an Iranian scientist examined the individual and combined effects of two pathogens on the growth and yield of winter wheat produced under natural conditions in an outdoor nursery. Hajihassani et al. (2013) reported that root-lesion nematode alone decreased wheat yield by up to 31 percent and *Fusarium culmorum* reduced yield by 22 percent. When these pathogens were both present, the grain yield was reduced by 63 percent. Results of that study have led to an increasing level of attention to studies with combinations of pathogens, which is the normal circumstance in commercial agriculture, but is also much more difficult to study.

Common root rot

A disease caused by *Helminthosporium sativum* was first detected on wheat at the Sherman Station by Dr. Hurley Fellows during a time when he was surveying crops for the presence of another disease (see the previous eyespot section). After a follow-up trip to Sherman County during 1931, Fellows sent a letter to David Stephens, dated July 27, 1931. Fellows stated that "*We were looking for another kind of foot-rot* [eyespot] *much different from the one Sprague* [Roderick Sprague, Bureau of Plant Industry, Corvallis, Oregon, who was studying what is now called Fusarium crown rot] *is working with and found it in abundance on your station* [the Sherman Station]. *Also, … I was surprised to find this Helminthosporium foot-rot there … The same thing is present in all the dryland regions from the Panhandle of Texas to Canada … We found it at Pendleton on the station farm also. Southern Idaho is full of it.*" Fellows letter then continued by explaining his discovery on the Sherman Station of three additional diseases caused by other species of *Helminthosporium*; barley stripe disease (*H. gramineum*), barley net blotch (*H. teres*) and barley spot blotch (*H. sativum*). It was Dr. Fellows, from Kansas, who discovered the presence of these four diseases that had not been detected by pathologists from Corvallis and Pullman. The next mention of common root rot at the dryland stations occurred in the 1950 Sherman Station Annual Report. During the late 1940s and early 1950s, the Sherman Station participated in a nation-wide comparison of 2-row and 6-row barley varieties and breeding lines. One year, in 1950, it was noted, without further explanation, that "*Helminthosporium sativum attacked some selections quite badly but not* others."

More recently, common root rot has not been considered an important disease in the region. The most likely reason is that most wheat is planted during the fall. Common root rot becomes important mostly on cereals planted during the spring. In a survey of foot rot pathogens in 288 winter wheat fields in 10 Oregon and Washington counties during the 1993 and 1994 crop years, Dr. Richard Smiley detected the common root rot pathogen in 3 percent of fields one year and 12 percent the next year. This pathogen was the dominant species of crown and culm rotting pathogens in only one county of Washington during one year (Smiley and Patterson, 1996). At about the same time, Smiley also quantified diseases that were present in the long-term experiments at the Pendleton Station (see Chapter 6). He determined that the common root rot pathogen was a minor component of a complex with two more prevalent pathogens that cause Fusarium crown rot (Smiley et al., 1996a). In field studies to compare pathogenicity of crown and culm rotting pathogens at Pendleton and Moro, the common root rot pathogen was much less damaging to both spring and winter wheat than the two pathogens that cause Fusarium crown rot (Smiley et al., 2005a).

Smiley used DNA-tests to examine the prevalence of soilborne pathogens in a current crop rotation experiment at the Sherman Station (see Chapter 12). He and his associates found that inoculum of the common root rot pathogen was present at exceedingly low concentrations and was only found in a treatment in which spring barley is produced annually (Smiley et al., 2013). That pathogen was not detected in any experiment where wheat was produced annually or in 2- or 3-year rotations. In similar tests for experiments at the Pendleton Station, they found that the common root rot pathogen was not present where winter wheat was the only cereal crop produced, or where winter wheat, spring wheat and fallow were managed as a 3-year rotation (Smiley et al., 2016). However, at Pendleton, the pathogen was present at sometimes high densities where spring wheat was produced annually, and in organic spring wheat produced in a 2-year rotation with fallow.

Cereal cyst nematode

During 1984, the cereal cyst nematode, *Heterodera avenae*, was discovered in eastern Oregon (Union County) and Washington (Whitman County). In 1986, Dr. Richard Smiley established the plant pathology research and extension program at the Columbia Basin Agricultural Research Center. Smiley and Gordon Cook, Union County Extension Agent, surveyed winter wheat fields in Union County and found that two-thirds of the fields were infested by cereal cyst nematode. Over the next three decades, Smiley conducted studies on the biology and control of that nematode. He ultimately estimated that the cereal cyst nematode reduced profitability of wheat production in the three Pacific Northwest states by about $4 million annually

(Smiley, 2009a). Research during the past decade suggests that the original estimate needs to be increased substantially.

Smiley conducted some of his research on cereal cyst nematode at the Cuthbert Farm (see Chapters 5 and 12). He examined effects of crop rotations, potential chemical controls, and susceptibilities of wheat, oats and barley varieties. All cereals were found to be susceptible to the pathogen and no chemicals other than aldicarb (Temik) were effective for reducing injury to the plant. However, aldicarb was not and could not be registered for application to wheat or barley. In a 5-year crop rotation experiment, yields of annual winter wheat were 40 to 60 percent less than for wheat alternated with fallow or any other crop except alfalfa contaminated with grass weeds (Smiley et al., 1994). One- and two-year breaks from winter wheat provided effective control of the nematode at that site. Effective breaks included fallow, pea, and weed-free alfalfa. The scientists showed that wheat yield declined in direct proportion to the density of the nematode in soil before the crop was planted. Smiley also noted that combined damage from the nematode and several fungal root pathogens were more highly correlated with a decline of winter wheat yield than for any one of the pathogens considered individually.

Irregular height of wheat plants caused by cereal cyst nematode near La Grande

Smiley et al. (1994) also determined in the crop rotation study that invasive juveniles of *H. avenae* emerged (hatched) from the protective cyst primarily during mid-spring. They then expanded their research to studies of the nematode on both spring wheat and winter wheat in dryland and irrigated fields of Union County (Smiley et al., 2005c). They refined relationships between nematode densities in soil and reduction in wheat yield, and found that an application of aldicarb could improve yield as much as 24 percent.

Smiley then expanded his research to sites in eastern Washington and eastern Idaho, where densities of this nematode were even higher and, compared to sites in Oregon, were less-heavily contaminated by fungal pathogens. After Smiley expanded his research into all three states, the commodity commissions established a Tri-State Nematology Research Agreement in which funds were contributed equally by the Oregon Wheat Commission, Idaho Wheat Commission, and Washington Grains Alliance. Research was conducted at locations in Union County, Oregon, Whitman County, Washington, and Fremont County, Idaho. To facilitate that research, Smiley designed and constructed an elutriation device to more easily and effectively separate nematode cysts from soil. After much testing, Smiley failed to identify any chemical or biological nematicide that was effective and also capable of becoming registered commercially for application to wheat.

Smiley also tested varieties of wheat, barley and oats to determine their resistance or susceptibility to the cereal cyst nematode. In a series of greenhouse and field tests he and colleagues determined that both resistance (reduction of nematode reproduction) and tolerance (ability of the plant to yield well even if invaded) existed in Pacific Northwest wheat and barley; publications are shown in Appendix 3. Some varieties expressed tolerance levels equivalent to that achieved by applying aldicarb to a susceptible variety. However, tolerance and resistance were genetically unrelated; tolerant varieties were not necessarily resistant, and some resistant varieties were very sensitive to this pathogen (e.g., they were intolerant). Smiley (2016) therefore presented guidelines to assist growers in identifying varieties that expressed the best balance of resistance and tolerance.

During the course of this research on cereal cyst nematode, Smiley's research group developed DNA-based methods for identifying cereal cyst nematodes in soil (Yan and Smiley, 2010; Yan et al., 2013a). Almost immediately, Dr. Guiping Yan determined that one of the soils in Smiley's collection contained a cyst nematode species that had never before been detected in North or South America. They therefore reported the presence in North America of the species *Heterodera filipjevi* (Smiley et al., 2008b). Six years later, Smiley and Yan also identified that same new species as being present in eastern Washington (Smiley and Yan, 2015). In their tests, wheat varieties differed in susceptibility to these two species of cereal cyst nematode. A variety resistant to one species could be susceptible to the other species (Smiley and Yan, 2015). It therefore became critical for growers to make the correct choice of wheat or barley variety to match the species present in their field. Since it is exceedingly difficult to distinguish among these two species, Yan's DNA-based tests became a part of the testing services provided by many nematode diagnostic laboratories in other states and nations.

Wheat varieties adapted to the Pacific Northwest were crossed with donors of resistance genes to develop crossing populations, potentially leading to development of new varieties with improved genetic resistance. As was described for Fusarium crown rot in 2015, the nematode-resistant populations were distributed to public- and private-sector wheat breeders in Washington, Idaho, Montana and Colorado. Also, as with Smiley's research on Rhizoctonia root rot and Fusarium crown rot, his research on cereal cyst nematodes became a stepping stone for doctoral dissertations at Washington State University and the University of Idaho. Smiley served on the research oversight committees at those locations.

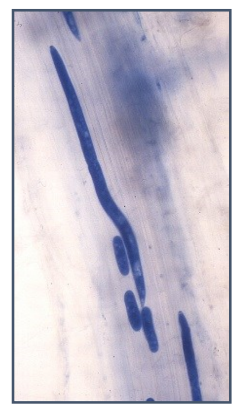
Breeding wheat for resistance to cereal cyst nematodes is now one of the research priorities at state universities in each of those states, and is a funding priority for the wheat industries in at least three of states. Smiley et al. (2017) published an international review of research on various aspects of the biology and control of cereal cyst nematodes.

Root-lesion nematode

High numbers of root-lesion nematodes were found in roots of winter wheat that was growing too slowly during the cool, wet spring of 1988. At that time, that nematode was thought to cause economic damage only in high-value irrigated crops. A decade later, Smiley learned about research in Australia that proved root-lesion nematodes to be exceedingly important in their dryland field crops. That discovery prompted Smiley to conduct a series of experiments to address three questions.

1) Do high numbers of these nematodes occur in dryland wheat fields in the Northwest?
2) If the answer is yes, do they actually retard wheat growth and yield in our region?
3) If that answer is also yes, what can growers do to minimize that damage?

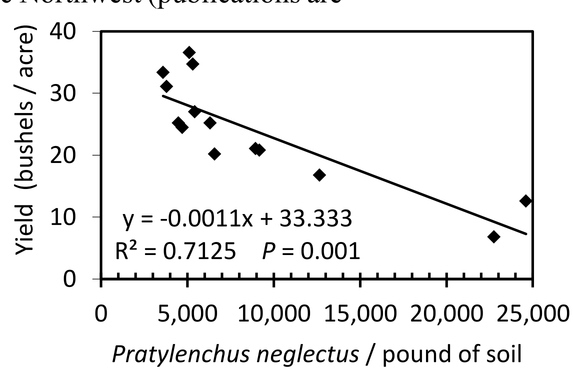
In 1999 and 2000, Smiley surveyed nematodes in 130 non-irrigated and 18 irrigated wheat fields in six Oregon and four Washington counties. Root-lesion nematodes were detected in 95 percent of the dryland fields and in all of the irrigated fields (Smiley et al. 2004). Two species (*Pratylenchus neglectus* and *P. thornei*) were detected and they occurred either alone or in mixtures. The nematode density was greatest in fields cropped at least every other year, and was not affected by the type of tillage. Nematode numbers were high enough to potentially reduce grain yield in about one-quarter of the fields. At about the same time, Smiley determined that the yield of winter wheat in a conservation tillage experiment at the Shaw Farm, near Pilot Rock (see Chapter 5), was inversely associated with the density of root-lesion nematodes (see the following chart). That observation provided the first evidence that these nematodes might be reducing wheat yields in our region. Remarkably, there was no above-ground symptom associated high populations of the nematode.



Root-lesion nematodes in a wheat root (revealed by a biological stain)

Additional crop loss studies were conducted and the results repeatedly confirmed that both of the root-lesion nematode species were reducing the productivity of winter and spring wheat in the Pacific Northwest (publications are shown in Appendix 3). Yields were reduced as much as 36 percent where the nematode was the only pathogen detected, and as much as 71 percent is soils where other soilborne pathogens were also present. Application of the non-registered aldicarb nematicide (Temik) could sometimes cause a doubling of yield for particularly susceptible varieties.

Smiley et al. (2008a) showed that root-lesion nematodes could thrive at depths in soil that would protect them from any shallow treatment practices. The highest numbers of nematodes in some soil profiles occurred in the second- or third-foot below the soil surface.



Yield of winter wheat relative to population density of root-lesion nematode near Pilot Rock during 1999

Smiley and Machado (2009) also examined the effects of crop rotations on root-lesion nematodes in an experiment at the Sherman Station (see Chapter 12). They determined that the numbers of these nematodes became greater as the frequency of host crops was increased in the rotation. The numbers were higher after harvesting spring mustard, spring wheat, winter wheat or winter pea than after harvesting spring barley, spring pea or camelina. Similar relationships were detected in commercial fields. Curiously, Smiley and Machado also detected that winter wheat was selecting for an abundance of *P. neglectus* and spring wheat was selecting *P. thornei*. That observation was confirmed during experiments at two locations near Pendleton, and on adjacent dryland wheat farms in eastern Idaho, where only winter wheat or spring wheat were produced on each farm.

At the Sherman Station, Smiley and Machado (2009) also determined that the root-lesion nematode reduced the plant extraction of soil water by as much as 50 percent. The nematode reduced root development, which imposed the equivalent of premature drought and a reduction in wheat yield. After harvest, the unused water remained in the soil profile.

Studies to find ways to minimize the nematode damage were initiated. Barley was found to be more tolerant than wheat, and could be a good rotation crop wherever 3-year rotations are profitable (Smiley, 2009b; Smiley and Machado, 2009). Wheat varieties varied greatly in tolerance to root-lesion nematodes (Smiley, 2009b). Unfortunately, a variety that was tolerant to invasion by *P. neglectus* was not necessarily tolerant to *P. thornei*. Yields of varieties that were the least tolerant could be doubled by an application of the non-registered nematicide aldicarb.

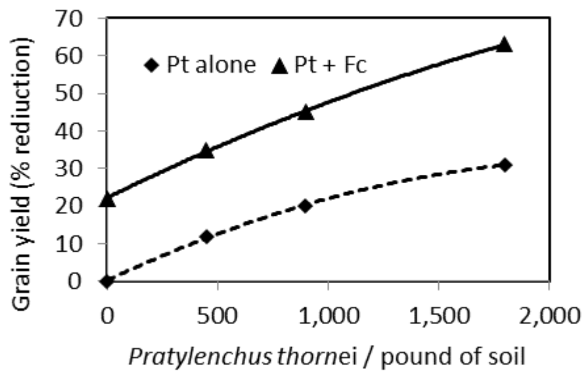
It became clear that studies of genetic resistance would need to be conducted separately for these nematode species, and that it would be important to know which species was present in each field. But distinguishing one species from the other was difficult, time consuming, and often resulted in errors. Smiley's group therefore designed and published DNA-based tests to improve the speed and accuracy of identifying root-lesion nematodes (Yan et al., 2008, 2013b). These molecular tests became widely used in public- and private-nematology laboratories in this and other countries.

Spring wheat yielded twice as much grain in soil infested by root-lesion nematode at the Pendleton Station after aldicarb nematicide was banded below the seed at the time of planting (left), as compared to what had been considered the 'normal' yield for that same variety (right)

Studies of genetic resistance under greenhouse and field conditions led to the discovery that several landrace wheat lines, originally identified as resistant to root-lesion nematodes in Australia, were almost totally resistant to invasion by both root-lesion nematode species present in Oregon's dryland wheat fields (Smiley et al., 2014a). While the production of the landraces greatly reduced the number of lesion nematodes in field soils, those landraces were also intolerant of attacks by the nematodes; i.e., their yield decreased markedly in the presence of the nematode. That finding demonstrated the need for commercial varieties that are both tolerant and resistant. An extension brochure was published (Smiley, 2015) to identify for growers the balance among these two traits among commercial wheat varieties in the Pacific Northwest.

Smiley also determined that significant numbers of root-lesion nematodes were present when conservation grasslands were converted into wheat production. Little was known about the reproductive capacity of the two species of nematodes on rangeland plants, weeds, or various types of agricultural crops. Screening experiments were conducted in the greenhouse to categorize both lesion nematode species for their ability to multiply on 18 types of range plants, 16 common weed species, and 30 species and varieties of crop plants (Smiley et al., 2014b, 2014c). Each of the plants were categorized as favorable for reproduction of both nematode species, only one species, or neither species. For instance, the jointed goatgrass weed was a very good host for both nematode species. Canola and mustard were favorable hosts for *P. neglectus* but not *P. thornei*, and the opposite was true for most varieties of peas and lentils.

Smiley participated in a study of effects of two pathogens on growth and yield of winter wheat produced in Iran. Hajihassani et al. (2013) reported that root-lesion nematode alone decreased wheat yield by up to 31 percent and *Fusarium culmorum* alone reduced yield by 22 percent. When these pathogens were both present, the grain yield was reduced by 63 percent, indicating a need for more studies with combinations of pathogens.



Relationship between yield reduction for dryland winter wheat and the population density of *Pratylenchus thornei* placed into soil either alone (dotted line) or with *Fusarium culmorum* (solid line). The *Fusarium*-alone treatment is the value for 'Pt + Fc' at the '0' rate of nematode population. Data were averaged over two harvests (2011 and 2012)

Smiley's research on root-lesion nematodes became a stepping stone for two dissertations at Washington State University. Notably, one of those dissertations was by one of Smiley's former technicians, Alison Thompson. She developed a genetic cross during her work at the Pendleton Station, and then refined and advanced that cross during her doctoral studies at Pullman. That research led to the development of a wheat mapping population that scientists could use to identify genetic resistance to root-lesion nematodes (Thompson et al., 2015). Later, that mapping population was found to also possess resistance to Rhizoctonia root rot, Fusarium crown rot and cereal cyst nematode (Thompson et al. 2017). That germplasm became an important component of state and federal wheat breeding programs at Washington State University and elsewhere.

As also described previously, other genetic populations from crossings between locally-adapted varieties and donors of resistance genes were developed in Smiley's program at Pendleton. Those genetic lines were distributed to public- and private-sector wheat breeders in Washington, Idaho, Montana, Colorado and South Dakota. Breeding wheat for resistance to root-lesion nematodes is now one of the research priorities at state universities in each of those states, and is an especially high priority for funding by the wheat industries in at least three of those states.

Based upon this research, Smiley (2009b) estimated that root-lesion nematodes reduce wheat profitability in the three Pacific Northwest states by at least $51 million annually. That estimate is now considered to have been conservative.

Other Diseases

Isolated occurrences of several other diseases have also been observed. Those diseases include a complex of root rots of peas and other legumes, stem rots of canola and mustard, snow molds of cereals, take-all root rot and powdery mildew. Each of those diseases are studied at other regional universities and did not rise to the level of sustained research subjects at the Pendleton Station.

One curious disease appears infrequently but has a long history in the region. It became the subject of some research and considerable extension communications. The first apparent documentation of this disease was in 1952. The contents of a letter sent from Dr. Charles Rohde to Dr. Wilson Foote (Farm Crops Department at Oregon State College, at Corvallis), dated April 10, 1952, stated "*I am enclosing some specimens of winter wheat plants which are causing the farmers around here some concern. I first noticed them in my plots about three weeks ago, but since they appeared in all varieties I thought it was some physiological disturbance which was probably common around here. They vary from complete albinism to some with chlorotic streaking of the leaves. Some appear to be sending out green leaves but many of them*

I am sure are nearly dead and I am sure will die. These plants were picked out of the field southwest of the buildings and the counts I made showed they occurred at a frequency of about 2 to 3%. Some farmers say they have a much higher percentage. … I would appreciate any information you might have concerning the reason for the appearance of these." Mr. Sam Dietz, of the Department of Botany and Plant Pathology at Corvallis sent a related response to Mr. Victor Johnson, the Umatilla County Extension Agent. Dietz's letter dated April 25, 1952 indicated that they failed to find any fungi or nematodes associated with the albino leaves on affected plants. They thought it might be caused by some abiotic feature of the soil. Several years later, Rohde sent a letter, dated March 8, 1954, to H. J. O'Reilly, Extension Plant Pathologist at Oregon State College, Corvallis, that "… *I have not noticed the presence of albino wheat plants in the field this year. However, in the spring of 1952 … I staked a number of these plants and observed them. Those which were completely albino soon died; however, many which had streaks of green in the leaves, later produced normal leaves and heads. I saved the seed of a number of these heads and planted them in the fall of 1952. These all produced normal plants last year and no albinism was observed. It would appear to me therefore, that this condition is caused by certain environmental conditions. … In talking with Dr. Vogel at Pullman regarding this, he informed me that he has observed this for twenty years and some years it is worse than others. He said that varieties, such as Elgin and Elmar, appear to be more susceptible to this condition than other varieties*."

The issue of albino plants reoccurs infrequently but stirs up discussion each time. It was pronounced on very low percentages of winter wheat plants during 1989, 1998, 1999 and 2001, and was investigated each time. Fully bleached plants die as seedlings during early spring, but those plants are widely spaced and do not cause yield loss because they the adjacent healthy plants to fill that space and prosper. It is now believed that this albinism occurs in wheat and barley as a result of some poorly-documented interaction of plant genetics and the environment. Smiley (2010) illustrated and described this anomaly.

***References*:**

Annual Reports from the Sherman and Pendleton Stations (Appendices 5 and 6)

Letters sent to or from the Station Superintendents

Brumfield, K. 1968. This was Wheat Farming: A pictorial history of the farms and farmers of the Northwest who grow the Nation's bread. Bonanza Books, New York. 191 pages.

Farr, D. F., G. F. Bills, G. P. Chamuris, and A. Y. Rossman. 1989. Fungi on Plants and Plant Products in the United States. APS Press, St. Paul, MN. 1252 pages.

Fischer, G. W. 1953. Manual of the North American Smut Fungi. The Ronald Press, New York. 343 pages.

Hajihassani, A., R. W. Smiley, and F. J. Afshar. 2013. Effects of co-inoculations with *Pratylenchus thornei* and *Fusarium culmorum* on growth and yield of winter wheat. Plant Disease 97:1470-1477.

Hall, W. E. 1959. History of Wheat Varieties in Sherman County. An Unpublished Paper. 5 pages.

Haskell, R. J., and J. I. Wood. 1923. Diseases of cereal and forage crops in the United States in 1922. Pages 164-266. In USDA, Bureau of Plant Industry, Plant Disease Survey Bulletin, Supplement 27. Washington, D.C. 546 pages.

Malik, V. S., and D. E. Mathre (editors). 1997. Bunts and Smuts of Wheat; an International Symposium. North American Plant Protection Organization, Ottawa, Canada. 445 pages.

Heald, F. D. 1915. Bunt or Stinking Smut of Wheat. Washington Agricultural Experiment Station Bulletin 126.

Kroese, D. R., S. Bag, K. E. Frost, T. D. Murray, and C. H. Hagerty. 2018. Diagnostic Guide: Wheat Soil-Borne Mosaic. Plant Health Progress 19:163-167.

Lucas, P., R. W. Smiley, and H. P. Collins. 1993. Decline of Rhizoctonia root rot on wheat in soils infested with *Rhizoctonia solani* AG-8. Phytopathology 83:260-265.

Matanguihan, J. B., K. M. Murphy, and S. S. Jones. 2011. Control of common bunt in organic wheat. Plant Disease 95:92-103.

McGregor, A. C. 1982. Counting Sheep: From open range to agribusiness on the Columbia Plateau. University of Washington Press, Seattle. 482 pages.

Murray, T. D., H. R. Pappu, and R. W. Smiley. 2009. First report of soilborne wheat mosaic virus on *Triticum aestivum* in Washington State. Online. Plant Health Progress doi: 10.1094/PHP-2009-1204-01-BR.

Poole, G. J., R. W. Smiley, T. C. Paulitz, C. A. Walker, A. H. Carter, D. R. See, and K. Garland-Campbell. 2012. Identification of quantitative trait loci (QTL) for resistance to Fusarium crown rot (*Fusarium pseudograminearum*) in multiple assay environments in the Pacific Northwest US. Theoretical & Applied Genetics 125:91-107.

Poole, G. J., R. W. Smiley, C. Walker, D. Huggins, R. Rupp, J. Abatzoglou, K. Garland-Campbell, and T. C. Paulitz. 2014. Effect of climate on the distribution of *Fusarium* species causing crown rot of wheat in the Pacific Northwest of the US. Phytopathology 103:1130-1140.

Powelson, R. L., and C. R. Rohde. 1972. The influence of date of seeding on control of Cercosporella foot rot with benomyl. Plant Disease Reporter 56:178-180.

Pumphrey, F. V., D. E. Wilkins, D. C. Hane, and R. W. Smiley. 1987. Influence of tillage and nitrogen fertilizer on Rhizoctonia root rot (bare patch) of winter wheat. Plant Disease 71:125-127.

Rasmussen, P. E., and C. R. Rohde. 1988. Stubble burning effects on winter wheat yield and nitrogen utilization under semiarid conditions. Agronomy Journal 80:940-942.

Scheuerman, R. D., and A. C. McGregor. 2013. Harvest Heritage: Agricultural origins and heirloom crops of the Pacific Northwest. Washington State University Press, Pullman. 186 pages.

Sitton, J., M. Wiese, B. Goates, R. Forster, R. Line, D. Mathre, C. Peterson, R. Smiley, and J. Waldher. 1995. Dwarf Bunt of Winter Wheat in the Northwest. Pacific Northwest Regional Extension Bulletin 489. 6 pages.

Smiley, R. W. 1997. Risk assessment for Karnal bunt occurrence in the Pacific Northwest. Plant Disease 81:689-692.

Smiley, R. W. 2009a. Occurrence, distribution and control of *Heterodera avenae* and *H. filipjevi* in the western USA. Pages 35-40. In: Cereal Cyst Nematodes: Status, Research and Outlook. (I. T. Riley, J. M. Nicol, and A. A. Dababat, editors). CIMMYT, Ankara, Turkey. 244 pages.

Smiley, R. W. 2009b. Root-lesion nematodes reduce yield of intolerant wheat and barley. Agronomy Journal 101:1322-1335.

Smiley, R.W. 2009c. Water and temperature parameters associated with winter wheat diseases caused by soilborne pathogens. Plant Disease 93:73-79.

Smiley, R. W. 2010a. Albinism. Pages 139-140. Compendium of Wheat Diseases and Insects, 3rd edition. (W. W. Bockus, R. L. Bowden, R. M. Hunger, W. L. Morrill, T. D. Murray, and R. W. Smiley, editors). APS Press, St. Paul, MN. 171 pages.

Smiley, R. W. 2010b. Chloride and zinc deficient leaf spots. Pages 143-144. Compendium of Wheat Diseases and Insects, 3rd edition. (W. W. Bockus, R. L. Bowden, R. M. Hunger, W. L. Morrill, T. D. Murray, and R. W. Smiley, editors). APS Press, St. Paul, MN. 171 pages.

Smiley, R. W. 2015. Root-lesion nematodes: Biology and management in Pacific Northwest wheat cropping systems. PNW Extension Bulletin 617, Oregon State University, Corvallis, OR. 14 pages.

Smiley, R. W. 2016. Cereal Cyst Nematodes: Biology and Management in Pacific Northwest Wheat, Barley and Oat Crops. PNW Extension Bulletin 620, Oregon State University, Corvallis, OR. 18 pages.

Smiley, R.W. 2019. Mechanized method to inoculate field soil to evaluate Fusarium crown rot of wheat. Plant Disease 1032857-2864.

Smiley, R. W., H. P. Collins, and P. E. Rasmussen. 1996a. Diseases of wheat in long-term agronomic experiments at Pendleton, Oregon. Plant Disease 80:813-820.

Smiley, R. W., A. A. Dababat, S. Iqbal, M. G. K. Jones, Z. Tanha Maafi, D. L. Peng, S. A. Subbotin, and L. Waeyenberge. 2017. Cereal cyst nematodes: A complex and destructive group of *Heterodera* species. Plant Disease 101:1692-1720.

Smiley, R. W., L.-M. Gillespie-Sasse, W. Uddin, H. P. Collins, and M. A. Stoltz. 1993a. Physiologic leaf spot of winter wheat. Plant Disease 77:521-527.

Smiley, R. W., J. A. Gourlie, S. A. Easley, and L.-M. Patterson. 2005a. Pathogenicity of fungi associated with the wheat crown rot complex in Oregon and Washington. Plant Disease 89:949-957.

Smiley, R. W., J. A. Gourlie, S. A. Easley, L.-M. Patterson, and R. G. Whittaker. 2005b. Crop damage estimates for crown rot of wheat and barley in the Pacific Northwest. Plant Disease 89:595-604.

Smiley, R. W., J. A. Gourlie, G. P. Yan, and K. E. L. Rhinhart. 2014a. Resistance and tolerance of landrace wheat in fields infested with *Pratylenchus neglectus* and *P. thornei*. Plant Disease 98:797-805.

Smiley, R. W., R. E. Ingham, W. Uddin, and G. H. Cook. 1994. Crop sequences for managing cereal cyst nematode and fungal pathogens of winter wheat. Plant Disease 78:1142-1149.

Smiley, R. W., and S. Machado. 2009. *Pratylenchus neglectus* reduces yield of winter wheat in dryland cropping systems. Plant Disease 93:263-271.

Smiley, R. W., S. Machado, J. A. Gourlie, L. C. Pritchett, G. P. Yan, and E. E. Jacobsen. 2013. Influence of semi-arid cropping systems on root diseases and inoculum density of soilborne pathogens. Plant Disease 97:547-555.

Smiley, R. W., S. Machado, K. E. L. Rhinhart, C. L. Reardon, and S. B. Wuest. 2016. Rapid quantification of soilborne pathogen communities in wheat-based long-term field experiments. Plant Disease 100:1692-1708.

Smiley, R. W., K. Merrifield, L.-M. Patterson, R. G. Whittaker, J. A. Gourlie, and S. A. Easley. 2004. Nematodes in dryland field crops in the semiarid Pacific Northwest USA. Journal of Nematology 36:54-68.

Smiley, R. W., A. G. Ogg, Jr., and R. J. Cook. 1992. Influence of glyphosate on severity of Rhizoctonia root rot, growth, and yield of barley. Plant Disease 76:937-942.

Smiley, R., and L.-M. Patterson. 1995. Seed treatments and genetic resistance for controlling smut diseases in winter wheat. Oregon Agricultural Experiment Station Special Report 946:81-95.

Smiley, R. W., and L.-M. Patterson. 1996. Pathogenic fungi associated with Fusarium foot rot of winter wheat in the semiarid Pacific Northwest USA. Plant Disease 80:944- 949.

Smiley, R. W., L.-M. Patterson, and C. W. Shelton. 1996b. Fungicide seed treatments influence emergence of winter wheat in cold soil. Journal of Production Agriculture 9:559-563.

Smiley, R. W., J. G. Sheedy, and S. A. Easley. 2008a. Vertical distribution of *Pratylenchus* spp. in silt loam soil of Pacific Northwest dryland crops. Plant Disease 92:1662-1668.

Smiley, R. W., and W. Uddin. 1993. Influence of soil temperature on Rhizoctonia root rot (*R. solani* AG-8 and *R. oryzae*) of winter wheat. Phytopathology 83:777-785.

Smiley, R. W., W. Uddin, P. K. Zwer, D. J. Wysocki, D. A. Ball, T. G. Chastain, and P. E. Rasmussen. 1993b. Influence of crop management practices on physiologic leaf spot of winter wheat. Plant Disease 77:803-810.

Smiley, R. W., and D. E. Wilkins. 1992. Impact of sulfonylurea herbicides on Rhizoctonia root rot, growth, and yield of winter wheat. Plant Disease 76:399-404.

Smiley, R. W., and D. E. Wilkins. 1993. Annual spring barley growth, yield and root rot in high- and low-residue tillage systems. Journal of Production Agriculture 6:270-275.

Smiley, R., D. Wilkins, W. Uddin, S. Ott, K. Rhinhart, and S. Case. 1989. Rhizoctonia root rot of wheat and barley. Oregon Agricultural Experiment Station Special Report 840:68-79.

Smiley, R. W., D. E. Wilkins, and E. L. Klepper. 1990. Impact of fungicide seed treatments on Rhizoctonia root rot, take-all, eyespot, and growth of winter wheat. Plant Disease 74:782-787.

Smiley, R. W., R. G. Whittaker, J. A. Gourlie, S. A. Easley, and R. E. Ingham. 2005c. Plant-parasitic nematodes associated with reduced wheat yield in Oregon: *Heterodera avenae*. Journal of Nematology 37:297-307.

Smiley, R. W., and H. Yan. 2009. Variability of Fusarium crown rot tolerances among cultivars and lines of spring and winter wheat. Plant Disease 93:954-961.

Smiley, R. W., and G. P. Yan. 2015. Discovery of *Heterodera filipjevi* in Washington and comparative virulence with *H. avenae* on spring wheat. Plant Disease 99:376-386.

Smiley, R. W., G. P. Yan, and J. A. Gourlie. 2014b. Selected Pacific Northwest rangeland and weed plants as hosts of *Pratylenchus neglectus* and *P. thornei*. Plant Disease 98:1333-1340.

Smiley, R. W., G. P. Yan, and J. A. Gourlie. 2014c. Selected Pacific Northwest crops as hosts of *Pratylenchus neglectus* and *P. thornei*. Plant Disease 98:1341-1348.

Smiley, R. W., G. P. Yan, and Z. A. Handoo. 2008b. First record of the cyst nematode *Heterodera filipjevi* on wheat in Oregon. Plant Disease 92:1136.

Smith, J. D., K. K. Kidwell, M. A. Evans, R. J. Cook, and R. W. Smiley. 2003a. Evaluation of spring cereal grains and wild *Triticum* germplasm for resistance to *Rhizoctonia solani* AG-8. Crop Science 43:701-709.

Smith, J. D., K. K. Kidwell, M. A. Evans, R. J. Cook, and R. W. Smiley. 2003b. Assessment of spring wheat genotypes for disease reaction to *Rhizoctonia solani* AG-8 in controlled environment and direct-seeded field evaluations. Crop Science 43:694-700.

Sprague, R. 1950. Diseases of Cereals and Grasses in North America; Fungi, Except Smuts and Rusts. The Ronald Press, New York. 538 pages.

Stephens, D. E., and H. M. Woolman. 1922. The Wheat Bunt Problem in Oregon. Agricultural Experiment Station Bulletin 188, Oregon Agricultural College and USDA Office of Cereal Investigations, Corvallis. 42 pages.

Thompson, A. L., A. K. Mahoney, R. W. Smiley, T. C. Paulitz, S. Hulbert, and K. Garland-Campbell. 2017. Resistance to multiple soil-borne pathogens of the Pacific Northwest is co-located in a wheat recombinant inbred line population. G3 (Genes, Genomes, Genetics) 7:1109-1116.

Thompson, A. L., R. W. Smiley, and K. Garland-Campbell. 2015. Registration of the 'LouAu' (Louise/IWA8608077) wheat recombinant inbred line mapping population. Journal of Plant Registrations 9: 424-429.

Tisdale, W. H., J. E. Martin, F. N. Briggs, W. W. Mackie, H. M. Woolman, D. E. Stephens, E. F. Gaines, and F. J. Stevenson. 1925. Relative Resistance of Wheat to Bunt in the Pacific Coast States. USDA Department Bulletin No. 1299. US Government Printing Office, Washington, D.C. 29 pages.

Woolman, H. M. 1914. Stinking smut of wheat. Washington Agricultural Experiment Station Popular Bulletin No. 73. 8 pages.

Woolman, H. M., and H. B. Humphrey. 1924. Summary of the literature on bunt or stinking smut of wheat. U.S. Department of Agriculture Bulletin No. 1210. 44 pages.

Yan, G. P., R. W. Smiley, P. A. Okubara, A. Skantar, S. A. Easley, J. G. Sheedy, and A. L. Thompson. 2008. Detection and discrimination of *Pratylenchus neglectus* and *P. thornei* in DNA extracts from soil. Plant Disease 92:1480-1487.

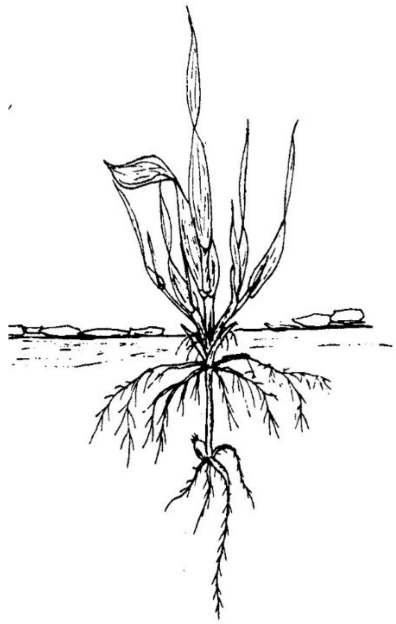
Yan, G. P., and R. W. Smiley. 2010. Distinguishing *Heterodera filipjevi* and *H. avenae* using polymerase chain reaction-restriction fragment length polymorphism and cyst morphology. Phytopathology 100:216-224.

Yan, G. P., R. W. Smiley, P. A. Okubara, and A. M. Skantar. 2013a. Species-specific PCR assays for differentiating *Heterodera filipjevi* and *H. avenae*. Plant Disease 97:1611-1619.

Yan, G. P., R. W. Smiley, P. A. Okubara, A. M. Skantar, and C. L. Reardon. 2013b. Developing a real-time PCR assay for detection and quantification of *Pratylenchus neglectus* in soil. Plant Disease 97:757-764.

Zwer, P. K. and C. O. Qualset. 1992. Genes for resistance to stripe rust in four spring wheat varieties 1. Seedling responses. Euphytica 58:171-181.

Zwer, P. K., and C. O. Qualset. 1994. Genes for resistance to stripe rust in spring wheat varieties. 2. Adult plant responses. Euphytica 74:109-115.



Chapter 21 - Weeds

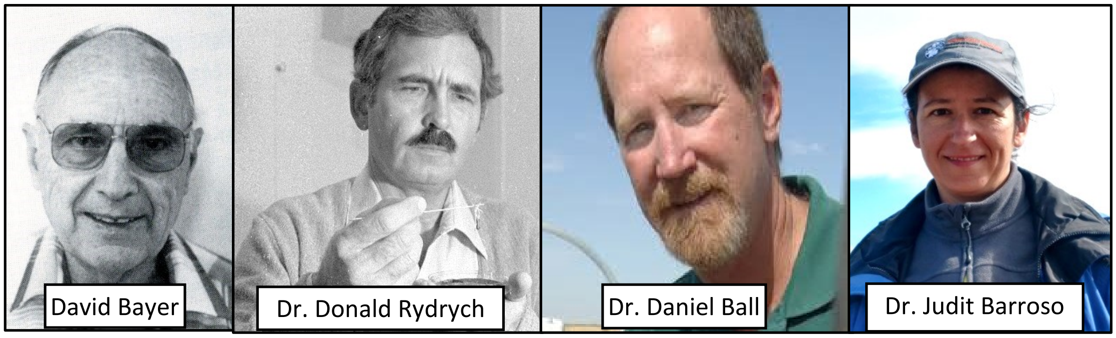
Management of weeds has always been challenging at the Sherman and Pendleton Stations. During the second year of research at the Sherman Station, Superintendent David Stephens stated in the 1912 Annual Report that "*The two most serious problems of the year, so far as experimental results are concerned, were the weeds and the mixing of varieties*." "*The most prevalent weeds, which were also the most difficult to control, were Russian thistle, tumble weed (Amaranthus albus) and tumbling mustard (Sisymbrium altissimum). Much time was spent trying to control the weeds and to rogue grain varieties*." In 1913 Stephens reported that "*weeds were again the most important controllable factor influencing experimental results. However, with available funds, it was impossible to eliminate weeds from all the experimental plats, though all of the fallow ground was kept clean*." The method used to keep the fallow ground free from weeds was the introduction of the 'bar weeder,' a 12-foot square rod drawn horizontally below the soil surface using a team of four horses. "*On large farms in the area, fields became so heavily infested by Russian thistle and tumbling mustard that it was nearly impossible to harvest those fields. The most urgent of needs at the station this year are to install a woven wire fence around the station farm and to get an increased appropriation to help control the weeds on the station*." The fencing intercepted migrating weeds before they blew across the experimental areas. Today, tumbling mustard is called tumble mustard or Jim Hill mustard.

In 1913, it was impossible to control weeds by hand hoeing the experimental plots that had thin stands. The workers made notes and, when results were being summarized, the weed-infestation notes were used to eliminate non-representative data so that the performance of crops in those treatments could be more accurately assessed. Stephens reported in a June 8, 1916 letter to M. A. Carleton, Senior Agronomist in the Office of Cereal Investigations, Bureau of Plant Industry, in Washington, D.C., "… *I believe there never has been so many weeds. Some fields of grain* [winter wheat] *are entirely overrun with tarweed and* [tumble] *mustard*."

Again, in 1919, the report indicated that Russian thistle was so prolific in plots cropped only to spring grains that they had to convert those plots over to tests of winter cereals, where the thistle could be managed much more effectively, and thereby reduce the numbers of seeds left in the soil. At that time, the scientists concluded that it was essentially impossible to control Russian thistle in spring grains. They also noted that weeds problems were greater when crops were planted at lower seeding rates. Russian thistle was again troublesome in all of the rotation plots planted to spring grains or field pea during 1920, but "*was not troublesome in plats planted to winter wheat*."

The same challenges continued to face the agronomists and wheat breeders at the dryland research stations through the 1940s. The first of six formally-trained weed scientists at the Pendleton Station was Mr. David E. Bayer (see Appendix 2), who was appointed in 1953 to conduct research on weed problems in six eastern Oregon counties. He resigned after one year to pursue a Ph.D. degree in Wisconsin, whereupon he spent the rest of his long career at the University of California, at Davis. The five long-serving weed scientists were Drs. Dean Swan (1955-1965), Don Rydrych (1965-1990), Dan Ball (1991-2013) and Judit Barroso (2014-present). During 1962 and 1963, Dr. Arnold Appleby served in an interim appointment when Swan took a study leave to earn a Ph.D. degree in Illinois. Appleby left the project in August 1963 to accept a professorial position at Corvallis, at which time Swan returned to the project. For several years during that transition, the role of the Sherman County weed extension agent, Martin Zimmerman, was expanded to include field trials in Sherman, Gilliam and Morrow counties. During that period, the Pendleton-based weed science project focused mostly on trials in Umatilla and Wasco counties. In 1965, when Dr. Rydrych moved his program from Washington State University to Pendleton, the station again began serving all eight counties of northcentral and northeast Oregon.

The weed scientists were each located at Pendleton but also served the Sherman Station and also established many field experiments on commercial farms to address weed problems throughout the eight-county region. For instance, almost immediately after his arrival, Rydrych established experiments with 24 named herbicides and 30 experimental formulations at 11 locations; the experiment stations in Pendleton, Moro and Hermiston, and off-station sites in Baker, Gilliam, Morrow, Sherman, Umatilla, Union, Wallowa and Wasco counties (see Weed Science Program Annual Reports, which are shown in Appendix 6).



David Bayer | Dr. Donald Rydrych | Dr. Daniel Ball | Dr. Judit Barroso

When Dr. Ball arrived at the Pendleton Station in 1991 he stated in his first annual report (Appendix 6) that "*An established weed science program in eastern Oregon will help to insure on-site, unbiased evaluation of weed control technologies in important cropping systems including cereal grains, pulse crops, fallow, and grass seed. The general philosophy of the weed science program will be to optimize the use of agricultural chemicals for maximum farm profitability and environmental protection. The philosophy considers the increasing costs of herbicides, and the overwhelming public concern for a clean environment. The difficulty with obtaining new herbicide registrations, loss of currently available herbicides, and the development of herbicide resistant weed populations, also make it important to limit the application of herbicides only to those uses which are most effective at controlling the target weed problems. This will help insure the future availability of important crop protection chemicals.*" In 2000, Ball conducted about 43 field experiments on many crops and crop management systems across the eight-county region of Oregon.

When the dryland stations were established, weed scientists published their results in the Station's annual reports (Appendices 5 and 6). Later, they published a separate annual report that was specific to the weed science program (Appendix 6; from 1953 to present), plus 79 peer-review papers in scientific technical journals (Appendix 3), and 39 reports in the research station's 'Special Reports' series, which was produced from 1976 until 2010 (Appendix 4).

The Weeds

The types and species of weeds investigated by these scientists is staggering. The rest of this chapter will focus on the most important findings from these experiments. As such, a compilation of individual weeds will not appear in later discussions. However a list of targeted weeds is presented to exemplify the diversity of tests performed. This list of weeds studied was compiled by reviewing all of the Weed Investigations Reports. It is assumed that this list is incomplete. For instance, studies were periodically reported for tests to control "broadleaf weeds." Also, some repetition is likely because different names were used by different reporters, as names evolved over decades.

Most research to control weeds is conducted at sites where they have already become problematic. That means that most experiments are conducted on commercial farms, because different weeds become problematic in different regions and under different crop management practices. Weed scientists have therefore conducted experiments at locations across northeast and northcentral Oregon, and in Idaho and Washington. Some experiments are conducted by using the grower's equipment to prepare large blocks of experimental plots. However, it is also common for weed scientists to transport equipment from Pendleton to off-station locations. This practice was particularly time-consuming and expensive for research involving mechanical methods of weed control.

Targeted Crops and Situations

An extensive array of crops were also the subject of research by these weed scientists. A great amount of emphasis was given to controlling weeds in fallow as well as 'in crop.' Other studies were conducted to examine potential persistence of herbicides that might affect growth of subsequent crops, to control weeds along roadsides, in fence rows, in experimental flower gardens and in tree windbreaks. Most individual experiments will not be discussed in detail. The following list of crops and management systems that were targeted for weed control research was also compiled by reviewing annual reports. The list is also presumed to be incomplete.

Weeds studied by scientists at the Sherman and Pendleton Stations

barnyard grass	field bindweed (morning glory)	prostrate knotweed
black nightshade	field pennycress	prostrate pigweed
blue flowering lettuce	flixweed	puncturevine
blue mustard	foxtail barley	purple mustard
bulbous bluegrass	giant reed (giant cane)	quackgrass
bur chervil	gromwell	rattail fescue
buttonweed	hairy nightshade	redroot pigweed
Canada thistle	henbit	restem filaree
catchweed bedstraw	horseweed	Russian knapweed
chickweed	Italian ryegrass	Russian thistle
China lettuce	ivy speedwell (Veronica spp.)	sandbur
coast fiddleneck	Jacob's ladder	scotch broom
common groundsel	jagged chickweed	shephard's purse
common lambsquarter	Japanese knotweed	speedwell
common mullein	tumble (or Jim Hill) mustard	tansy mustard
corn cockle	johnsongrass	tarweed
curly dock	jointed goatgrass	tumble pigweed
cutleaf nightshade	kochia	watergrass
dandelion	ladysthumb	western ragweed
diffuse knapweed	large crabgrass	white top
dodder	little mustard	wild buckwheat
downy brome (cheatgrass)	longspine sandbur	wild oat
eastern black nightshade	Medusahead rye	windgrass
false flax	miner's lettuce	witchgrass
fiddleneck tarweed	peppergrass	yellow sweetclover
	prickly lettuce	
volunteer crop plants (wheat, barley, alfalfa, radish, sugar beet, corn and potato)		

Crops and management studied by weed scientists at the Sherman and Pendleton Stations

alfalfa; irrigated or dryland, seed or hay	pasture; irrigated
asparagus	peas; green processing or dry, irrigated, or dryland
beans; various types	peppermint
canary grass	potato
canola; fall or spring, dryland or irrigated, herbicide-tolerant or regular	roadsides
cereal rye	safflower
chickpea	soybean
corn; sweet or field	spring barley; no-till or cultivated
fence rows	spring wheat; no-till or cultivated, herbicide-tolerant or regular
flax	strawberry
grape; wine vineyards	sugar beet
grass seed crops; fescues, perennial ryegrass & Kentucky bluegrass	summer fallow; no-till or cultivated
hybrid cottonwood	timothy
lentil; various types	tree windbreaks
mustard	watermelon
native grasses; bluegrasses, fescues, ryegrasses & wheatgrasses	white lupin
onion	winter barley; malting or feed
ornamental gardens; iris, tulip, rose, and others	winter wheat; no-till or cultivated, dryland or irrigated, in-crop tillage, herbicide-tolerant or regular

Reports of weed science research are particularly well expressed in annual reports and preserved correspondence from the stations prior to 1976. After 1976 the reports became more formal and less descriptive and, in 2010, the preparation of annual reports was terminated. For this historical treatise, it is of particular interest to illustrate the style of earlier reports and correspondence.

An Early Perspective of the Weed Problem

New weeds were often introduced shortly after railways were constructed into regions where wheat is now produced, as was discussed in Chapter 2. Introductions prior to 1900, or soon thereafter, included weeds such as Russian thistle (tumble weed), tumble mustard, tarweed, Canada thistle, morning glory (field bindweed), wild oat and China lettuce (McGregor, 1982). Early methods to control these weeds were ineffective. In 1922, Dave Stephens responded to a national survey on 'The American Weed Problem.' In a 3-page typewritten response, dated October 24, 1922, Stephens stated that weeds "*… on the dry lands of Eastern Oregon is very much of a tax on our agriculture because it greatly increases tillage requirements, the weeds compete with cropped plants for food, and the weeds compete with cropped plants for moisture*." Stephens went on to discuss what he considered to be the worst weeds. In grain crops, his list included tumble mustard, Russian thistle and field bindweed (morning glory). On fallow land he listed Russian thistle, tumble weed [now called kochia] and tumble mustard. He also discussed "*certain pernicious weeds*" such as Canada thistle and quack grass.

In 1928, in preparation for his appearance as an expert witness for a lawsuit, Dave Stephens wrote the following to an attorney in Portland. "*In regard to the actual amount of moisture used by the Russian thistle, … in a two years trial here we learned that the Russian thistle used about 400 times its own dry weight in water when allowed to mature. … Russian thistles require about as much water to produce an equal amount of dry matter as does the wheat crop*."

In the 1939 Sherman Station Annual Report, Merrill Oveson and Bob Hoskinson wrote: "*Just before the young spring wheat plants emerged there was a heavy infestation of knotweed (Polygonum aviculare) that started on the north slope. We were fearful that this thick stand of knotweed would offer too much competition to the young wheat plants, as well as reinfest the soil with a new crop of weed seeds. We therefore harrowed this north slope crosswise to the drill rows with a spike tooth harrow, having the teeth sloped at about a 45-degree angle. The result from this harrowing was very satisfactory. We obtained almost a complete kill of the knotweed and did not injure the young wheat plants to any noticeable extent. The stands were fully as thick and vigorous on the series harrowed as those not harrowed*." In the 1940 Annual Report they stated that the principal weeds in winter wheat fields were little mustard, tumble mustard and tar weed. In addition, they reported that prostrate knotweed became especially well established where wireworm (juveniles of the click beetle insect) thinned stands of late-maturing varieties.

Weed problems in eastern Oregon were perhaps best defined in the first annual report of the first long-serving weed scientist at Pendleton. In 1955, Dean Swan wrote the following introduction.

"*Weeds that trouble farmers fall into three classifications, those annual weeds that germinate, grow, and go to seed each year, deep rooted perennial weeds that come back up from the roots each year, and biennial weeds. These pests compete with the desired crop for moisture and soil nutrients and also, in many cases, lower the value of the crop*."

"*Annual weeds have troubled Columbia Basin farmers since they first began growing wheat in the area. Until the advent of 2,4-D about ten years ago the growers could not do much with these annual pests as cultural practices were about the only method he had for combatting weeds. Today, however, we have the selective hormone type herbicide which, when properly employed, can do an excellent job of selectively controlling most broadleaved weeds in wheat. But, due to so many factors such as time of application, temperature, type and rate of herbicide, stage of growth, etc., we do not always get the desired control or cause excessive injury to the cereal. Hence, there is a need for further study on this problem of annual weeds in winter wheat*."

"*The most troublesome perennial weed in the Columbia Basin is wild morning glory or field bindweed. Many acres of wheat are annually infested with this weed. Although there have been several control methods (mechanically and chemically) recommended they have not proved satisfactory. The wide spread use of chemical herbicides for the past ten years should have reduced the morning glory population but recent surveys show that the acreage is increasing instead of decreasing. With diverted acres and lower income the problem is becoming more acute to the farmer. High production is not possible with stands of morning glory competing for moisture and soil nutrients. Soil sterilants are a possibility but the large scale use of these compounds has too many disadvantages. There is a need for a large amount of research work to be conducted on this tenacious perennial weed*."

"*In the irrigated areas such as Stanfield, Hermiston, Irrigon, Milton-Freewater, etc. the weed control problems are many and varied. The alfalfa producers are troubled with infestations of annual and perennial weedy grasses which reduce alfalfa yield and also lower the quality of hay. Farmers with crops such as corn, sugarbeets, beans, watermelons, etc., are troubled with such weeds, as pigweed, lambsquarters, mustard, and several more annual broadleaf species. The growers in the sandy areas are also greatly troubled with sandbur and barnyard grass. In the peppermint fields one of the high costs of production is the hand hoeing of the weeds. All of the irrigators who have open ditches are consistently troubled with weed infestations in ditches and on the banks. This is a great source of contamination of weed seed carried out into the fields by the irrigation water*."

"*This annual report contains results of trials concerned with the previous mentioned problems. … All off-station trials were conducted in cooperation with the County Agents and farmers in the areas where the experiments were conducted*."

Long-term Off-Station Weed Research Facilities

Most weed-control research was conducted on commercial fields and research stations. However, weed research was also among the primary objectives on at least eight long-term off-station locations. The sites listed below were described in Chapter 5.

'Umatilla County Weed Experiment Station' east of the Pendleton Station; 158 acres leased for 10 years (1938-1948).
King Pilot Farm west of Helix; 75 acres leased for 13 years (1949-1962)
Hill Pilot Farm west of Helix; 75 acres leased for 9 years (1950-1959)
Crow Pilot Farm south of Weston; 75 acres leased for 14 years (1950-1964)
Gilliland Farm east of Pilot Rock (20 acres donated for 6 years (1993-1998)
Shaw Farm north of Pilot Rock (20 acres donated for 6 years (1994-1999)
Hennings Farm west of Ralston, WA; 25 acres donated for 12 years (1995-2007)
Jepsen Farm east of Heppner; 30 acres donated for 10 years (1999-2008),

Additional information regarding the Jepsen Farm was discussed in Chapter 12. The three 'pilot farms' were discussed in Chapter 13, and the Hennings Farm was discussed in Chapter 20. The following passages provide additional information about the other three locations that were specifically established for weed science research.

Umatilla County Weed Experiment Station

The objective of this station, also called the 'Morning Glory Farm,' was to reduce or eliminate reductions of winter wheat yields being caused by field bindweed. The specific objective was to find a way to control this weed without using the inorganic salt, sodium chlorate. Sodium chlorate was dangerous but very effective, and was the chemical of choice for controlling perennial weeds such as field bindweed, quack grass, Canada thistle, Russian knap weed, blue flowering lettuce, white top, scotch broom, and a large number of annual and biennial weeds. During the 1930s farmers used this salt to treat patches of soil infested by bindweed and other weeds. In 1938, George Mitchell wrote to USDA administrators in Washington, D.C. that "*Farmers in Umatilla county purchased 125,000 pounds of sodium chlorate alone for weed control in 1938. Morning glory is a very serious problem in this section.*"

Sodium chlorate was a soil sterilant. When placed into dry environment of eastern Oregon, the residual effects often persisted for many years or even a decade. Wheat crops either would not grow or were stunted in the treated soils. While it was a very efficient for the intended uses, and was therefore the compound of first choice for farmers who needed to control the weeds listed previously, its use was on a 'user-beware' basis. Sodium chlorate was very flammable and explosive. The label carried the wording "*Caution: … there is one thing that should be carefully observed. Sodium chlorate when mixed with organic material of any kind, such as dust or clothing, dried weeds, … is inflammable. Very serious fires may result … All clothing and shoes should be rinsed carefully after the user … has finished spraying. In spraying patches of weeds near sheds or buildings … keep fire, such as lighted matches, cigarette ashes, etc., from getting in the dry sprayed weeds. This point … of fire hazard is one which cannot be ignored …*"

Domestic production of chlorates was largely shifted to defense purposes during World War II. Imports of chlorates for agricultural uses were also forbidden. The availability of sodium chlorate became greatly restricted at a time when its use was the standard weed control practice in the Pacific Northwest. In 1941, the Eastern Oregon Wheat League lobbied Congress to divert more sodium chlorate into commercial wheat production. During the late 1930s it became clear that a safer way was needed for controlling field bindweed.

A 158-acre Umatilla County Weed Experiment Station was established in 1938, as described in Chapter 5. A 40-acre experimental block was planted to barley during 1938 and wheat during 1939. Both crops were failures due to the uniform and severe competition from the morning glory. George Mitchell and Walter Holt initiated studies to determine the optimum time to start cultivating for planting spring wheat and winter wheat, optimum number of days between morning glory emergence and cultivation, optimal depth of tillage, effect of alternating years of cultivation and cropping, choice of crop to plant, influence of cultivating immediately after harvest, effects of nitrogen fertilizer application, the most effective implement for each cultivation, and the most effective number of cultivations. Information learned from 1939 until 1943 was published by Harris and Mitchell (1944). They reported that the most economical and practical method to control morning glory was to alternate one year of properly-timed cultivations and one year of crop. Less economical, but also effective, was to quit planting crops and continuously cultivate the land until the weed had been eradicated.

Harris and Mitchell found that morning glory could be controlled by cultivation if the infested field was plowed within a few days after plants began to emerge, and then cultivate again within 8 to 12 days after each re-emergence. When the field was to be planted to a crop the soil should be plowed deeply just before planting and the seeding rate should be increased and enough fertilizer applied to develop a vigorous, dense stand of crop plants. The field should be cultivated again immediately after harvest and as needed during the fall to continue weakening the surviving morning glory plants. Those cultivations should be done with a sweep blade to preserve as much surface residue as possible for controlling erosion. These tillage-based systems to control morning glory were expensive and were only marginally successful. The farmers still preferred to apply sodium chlorate wherever morning glory had not yet infested entire fields.

Field days at the 'Morning Glory Farm' – 103 farmers attended in 1940

The scientists also evaluated newer herbicides as they became developed immediately after World War II. During 1944, the Morning Glory Farm became one of the first locations in the western U.S. to test the new and much publicized 2,4-dichlorophenoxyacetic acid. At that time 2,4-D was in a strictly experimental testing stage. Mitchell explained to the head of the Weed Investigations Unit of the USDA-BPI, in Washington, D.C. that "*We have had a great many inquiries about the new treatment, the Oregon weed people do not have any first hand information regarding the effectiveness of the chemical. Have you tried the 2,4-dichlorophenoxyacetic acid on morning glory, white top and Russian knapweed?*" "*We are somewhat afraid that since so little is known about the material that the farmers will try it, fail, and kill the material before we learn how to use it. All of the publicity on this material has been highly premature and ill advised to say the least.*"

For these initial investigations with 2,4-D, Mitchell recognized that he needed the assistance of the Weed Science Professor at Oregon State College. That assistance was slow to develop and relationships between the Pendleton Station and the Farm Crops Department at Oregon State College sometimes became fractious. Dr. Virgil Freed didn't feel an obligation to travel to Pendleton for that work, particularly since it was his opinion that "*... as yet it is impractical to consider putting this on too large an area .... it will cost in the neighborhood of $90.00 an acre from this material alone in combatting solid stands of weeds.*" That response agitated Mitchell, and that agitation became greatly amplified when the Farm Crops Department also decided they would keep the money ($5,184.09) from the grain Mitchell had recently sold from the experiments at the Morning Glory Farm. Mitchell therefore sent Freed a bill for repairs on the tractor that was used at the Morning Glory Farm, stating "*I can see no logical reason why the Farm Crops Dept. should get all this money as they do not contribute anything in time or money towards the operation of the Weed Station. We could use at least $2,500 towards the construction of a greenhouse to further our plant breeding work*." Ultimately, the Department conceded. On May 21, 1947, Mitchell received a letter stating "*On the basis of your letter of September 21, 1946, relative to the sale of wheat from the Weed Station, we set aside for the Pendleton Branch Station the sum of $2500 to be restricted to the construction of a greenhouse for plant breeding work at that station.*" The next year, when Mitchell submitted the check for grain sales to the Department, he stated "*I am enclosing checks from Inglehart Bros. Inc. and Pendleton Grain Growers for a total of $5871.27 for wheat sold off the Weed Station. Inasmuch as the work is all done from this station and none of the other departments have shown any interest in the work I hope that I may have some say as to how the money derived from sales of the surplus crops may be spent*." By 1948, Dr. Freed was conducting his own trials with 2,4-D at the Morning Glory Station, and by 1950 nearly all farmers in the region were successfully using 2,4-D to control most broadleaf weed species in their wheat crops. In 1957 and 1958, Dean Swan conducted comprehensive herbicide studies on the Morning Glory Farm and quantified the value being realized by farmers who treated infested fields with 2,4-D. He stated in his annual report that a high rate of 2,4-D increased wheat yield by 25 bushels/acre in areas that were heavily infested with field bindweed.

Gilliland and Shaw Farms

Dr. Dan Ball and colleagues investigated weed control in conservation tillage systems on two farms near Pilot Rock. The goal was to examine different systems for the combined ability to control downy brome, conserve soil and water, and improve farm profitability. The researchers also aimed to determine the best protocols for applying fertilizers, tilling the soil, and establishing crop stands in various conservation treatments.

At each farm, four replicates of seven treatments were established using half-acre plots and field-scale equipment. Treatments were:

1. Winter wheat/fallow rotation with fall tillage (harrow or disk) of grain stubble and chisel plowing in the spring (conservation tillage fallow)
2. Winter wheat/fallow rotation with herbicide applications as needed in the fall and spring (chemical fallow)
3. Winter wheat/spring barley/fallow rotation with fall stubble tillage and chisel plowing in the spring (conservation tillage fallow)
4. Winter wheat/spring barley/fallow rotation with herbicide applications as needed in the fall and spring (chemical fallow)
5. Winter wheat/fallow/canola rotation with fall stubble tillage and chisel plowing in spring (conservation tillage fallow)
6. Winter wheat/fallow rotation with no fall stubble tillage and moldboard plowing in the spring (the current standard practice)
7. Continuous no-till hard-red spring wheat (Shaw site only)

During the final year all plots were planted uniformly to winter wheat. Data was collected on weed species and populations, crop green cover during winter and spring, stubble and ground cover between crops, percent clods over 2-inch diameter, grain yield, plant diseases. Weeds of particular importance at these sites were downy brome, volunteer cereals, Russian thistle, prickly lettuce, and others (Ball et al., 2000).

During the final year in uniformly planted winter wheat, the downy brome densities at the Gilliland Farm were much greater where the 2-year wheat-fallow rotation had been maintained with chemical fallow (52 plants/yard^2) compared to the conservation tillage fallow (10 plants/yard^2) and the moldboard plowed fallow (1 plant/yard^2). In the 3-year rotations that included barley, downy brome was greater in the chemical fallow treatment (10 plants/yard^2) than in the conservation tillage fallow treatment (4 plants/yard^2). At the Shaw Farm the downy brome densities ranged from 2 to 10 plants/yard^2, with the highest density occurring in the chemical fallow treatment of the 2- and 3-year rotations and the lowest density occurring in the annual no-till hard red spring wheat treatment. No plant disease reached yield-limiting proportions at either location, although the diseases that were present and quantifiable included Rhizoctonia root rot, eyespot (strawbreaker root rot), take all, and root-lesion nematode. Winter wheat yield was inversely proportional to the density of root-lesion nematodes during the final year (Smiley et al., 2004).

Methods Used to Study Weeds and Weed Control

Many traditional as well as innovative and clever methods are used in the practice of weed science research. The most common studies are conducted by selecting an infested field, dividing the area into plots, applying various tillage or chemical treatments, and monitoring weed populations for vigor and/or survival. In planted trials, crop yields and product quality are measured. However, these types of experiments represent only a small sampling of the work of a weed scientist. For instance, Dr. Judit Barroso greatly increased the complexity of her field trials by dividing some fields into quadrants and then pre-treating each quadrant to create different weed species composition and density in those quadrants. Then, when the desired treatments were applied to those areas, she could determine the efficiency of the treatments against four different levels of 'weed pressure.' This is but one example of how the complexity of research can be increased to provide additional information.

Weed scientists often also evaluate how many weed seeds remain in soil after an experiment has been completed (Ball, 1992; Ball et al., 1998). It is not easy to distinguish weed seeds from soil particles. There are various ways in which weed seeds can be counted. The soil surface can be vacuumed, and the detritus taken to a laboratory where weed seeds are separated from crop residue. Seeds can be floated out of soil before being counted, or can be observed and counted directly using a magnifying lens or microscope. Alternatively, samples of soil can be mixed, moistened and incubated to encourage weed seeds to germinate so the seedlings can be counted and identified. These are but a few of the ways in which scientists conduct studies of weed seed banks.

In studies that require comparisons of weed populations, such as for studies of weeds suspected of having developed a resistance to an herbicide, spray trials can be conducted on weedy areas at locations where they occur naturally. However, there are intrinsic uncertainties about comparisons conducted under slight but important differences in local weather, soil chemistry and moisture, plant growth stage, and other environmental conditions. Precision in such research is gained by studying all populations at a central location to ensure that all potential differences in environment have been minimized or eliminated. Seeds are often collected and examined in the greenhouse or growth chamber. For weeds that are not easily or uniformly germinated under greenhouse conditions, it may be necessary to collect seedlings from field sites and transplant them into greenhouse pots or flats for side-by-side comparisons with plants from other field populations. Dr. Dan Ball also used a thermal-gradient plate upon which to determine optimal temperatures for germinating downy brome and jointed goatgrass seeds. That equipment allowed him to establish models to predict the date on which weed seedlings would emerge in the spring, or after the soil became moistened by rainfall in the fall (Ball et al., 1993, 1995, 2004).

Dr. Judit Barroso used a 'weed cart' that was pulled behind the harvest combine to collect and quantify the density of weed seeds that were being expelled from the combine and 'replanted' into the field. This is important because different weeds retain different numbers of viable seed at the time of harvest. Seeds of some species shatter early and drop to the ground before harvest (Barroso et al., 2015; Lyon et al., 2019; San Martin et al., 2019). The intent of such research is to find ways to reduce the weed 'seed bank' using a non-chemical method to progressively reduce weed densities over time. The practical importance of this procedure has already been recognized. Attachments have been constructed so that combines destroy weed seeds as they emerge with the chaff and other residues during harvest.

Some studies require more uniform or denser populations of weeds than can typically be found under natural field conditions. It is not uncommon for weed scientists to collect large volumes of weed seeds that are then distributed over a block of land. As an example, Drs. Dan Ball and Judit Barroso have intentionally planted weeds such as downy brome, jointed goatgrass, Russian thistle into fields at research stations so they can evaluate potential control measures. Barroso collected seeds of Russian thistle and planted them in greenhouse flats to generate what appeared to be a uniform lawn of thistle seedlings. Thousands of individual seedlings were then transplanted into a grid pattern in fields at both dryland research stations to provide the framework for a uniformly-infested weed control experiment.

Many clever types of equipment are used in weed science research. For instance, it is inherently difficult to be absolutely precise when applying an herbicide to plants being grown in the greenhouse. The same is true for pre-emergent or pre-plant herbicides being applied to the soil surface in greenhouse pots or flats. Dr. Dan Ball therefore constructed a mechanized spray chamber to which the plants could be moved temporarily while a spray boom moved across the pots or flats to be treated. After the plants or soils were treated they were moved back to the greenhouse for observation.

Several types of sprayers for use in field plots were described in Chapter 14 and in annual reports from the weed scientists. These innovations were based upon a spray system being mounted on a framework suspended by one- or two-bicycle wheels and moved manually by using handlebars held by the person making the application. To reduce the amount of time for changing from one herbicide to the next, or to a different concentration, Dr. Ball constructed a CO_2-pressurized backpack-style field-plot sprayer with a hand-held spray boom and plastic soda pop bottles. Many bottles could be pre-filled in a chemical laboratory and quickly changed from one bottle to the next while working in the field. This rapid and efficient system was an invaluable time saver and was especially important when spray applications needed to be made quickly, as when trying to finish the job before the wind became stronger.

In 1962, Dr. Arnold Appleby constructed a 'logarithmic' herbicide sprayer that systematically reduced the application rate as the sprayer moved through an experimental plot. The sprayer was useful for evaluating variable dosage rates applied as pre-plant soil incorporated, pre-emergence, post-emergence and in-crop herbicide applications for producing all crops. It was most often used for studies of downy brome and various broadleaf weeds in winter wheat, winter barley, and chemical fallow. Appleby's first uses of the logarithmic sprayer were on trials established for controlling downy brome at the Sherman Station and at the Thorne Ranch in Umatilla County. The herbicides were applied to fallow from March through May, and weed control data was collected during the summer. Then winter wheat was planted in the fall, and notes were taken of downy brome control and crop injury.

Appleby explained the mode of operation of the logarithmic sprayer using these words in the 1963 Weed Science Program Annual Report. "*This sprayer works on the principle of constant dilution of the spray mixture with an accompanying decrease in rate. These particular plots were 100 feet long. The rate decreased logarithmically from the front of the plot to the back, with the rate at the end of the plot being 2.5% of the original rate. Evaluation was made by laying out a tape measure along the plot and noting the distance at which the crops and weeds were no longer completely killed, a distance at which 50% control or injury was estimated, and the point at which no control or injury was seen. With the use of charts, the rate of chemical applied at these points was determined. This information is given as LD_{100}, which is the lowest rate at which 100% control is obtained, LD_{50}, and LD_0.*"

The logarithmic sprayer was used in large numbers of field trials for at least a decade. For instance, in 1971, Dr. Don Rydrych still used that sprayer to test logarithmic application rates for 26 treatment combinations of soil-incorporated, pre-plant, and post-emergence applications for controlling fiddleneck, purple mustard, corn cockle and cheatgrass in winter wheat and winter barley. Other weeds in those trials included smaller amounts of miner's lettuce, jagged chickweed, tumble mustard, and Jacobs ladder.

The foregoing examples are just a glimpse into the ways that scientists conduct research into the biology and control of weeds.

The Practice of Weed Control

Controlling weeds involves a combination of different practices. Individual weed control experiments generally examine one or two of those potential practices. The topics studied by the weed scientists at the Sherman and Pendleton stations have included 1) weed biology, 2) mechanical in-crop tillage, 3) mechanical tillage of fallow, 4) screening herbicides in crops, 5) screening herbicides in fallow, 6) crop rotations, 7) crop tolerance to herbicides, 8) crop avoidance of herbicides, 9) herbicide-resistance crops, 10) herbicide resistance in weeds, 11) herbicide persistence in soil, 12) herbicide drift, 13) stubble burning, 14) biological control, 15) killing weeds with electricity, 16) seed destruction during harvest, 17) influences of other agronomic practices, 18) weed-caused deterioration of native grass stands, 19) spot spraying of individual weeds, and 20) site-specific mapping of weed species and densities. Other scientists have also contributed to those studies.

Weed biology

A knowledge of the biology of weed plants is essential for developing effective weed control practices. Weeds are controlled best and most efficiently when control practices are applied at a weak point in the weed's life cycle, which differs for every type of weed and also among some species of individual genera of weed plants.

Today, it is common knowledge that some deep-rooted perennial weeds are not effectively killed by tillage practices, and that it does little good to spray winter annual grass weeds after they have already developed viable seed. That information was achieved through field observations as well as controlled scientific studies. Most studies of that type were conducted on campuses of universities, but some of the studies were conducted at Pendleton and Moro. Several examples of such studies are summarized.

In 1995, Dr. Daniel Ball conducted an herbicide application timing experiment with paraquat and glyphosate to determine effects of timing on seed production in downy brome and jointed goatgrass. Each field plot was seeded with a specific number of seed from one of those weeds. The timing of application for each herbicide created vast differences in the numbers of seeds produced. That information became incorporated into extension seminars, extension publications, and the labels for those herbicides. Similar studies had been conducted at Pendleton by Dr. Donald Rydrych, and are now being conducted by Dr. Judit Barroso.

In 2003, with downy brome, jointed goatgrass and several other winter-annual grass weeds, Dr. Ball studied the timing of seed set and viability with respect to heat units (growing degree days) accumulated through the growing season. He also determined the number of heat units required to stimulate the germination of seeds in soil. Similar studies with Nuttall's and weeping alkali grasses were conducted by Dr. Catherine Tarasoff, one of Ball's graduate students. This information enabled the development of weather-based predictions to estimate the date at which it would be too late to prevent production of viable seed (Tarasoff et al., 2007a, 2007b).

It was once thought that jointed goatgrass seeds only germinated in the fall and its growth was in synchrony with that of winter wheat during the remainder of the growing season. Several field observations challenged that concept. It appeared that some seed germinated in the spring and could set viable seed in spring wheat. If so, that would negate or compromise an important control practice recommended at that time; switching from winter wheat to spring wheat for the purpose of reducing the population of jointed goatgrass. To examine that issue, Dan Ball participated as an advisor in the doctoral dissertation of his former research assistant, Dr. Darrin Walenta. They found that spring-germinated jointed goatgrass could indeed set viable seed with a minimal vernalization requirement (Young et al., 2003a, 2003b). The finding from that research led to important revisions in recommendations for controlling jointed goatgrass (Yenish et al., 2009).

During the 1970s, Dr. Don Rydrych quantified the competitive effect of downy brome and corn cockle on growth and productivity of winter wheat (Rydrych 1974; 1981; Rydrych and Muzik, 1968). He determined how many plants per unit area were necessary to reduce wheat yield by a specific amount, presuming that the weather and soil were equivalent to those he studied. Nearly a half century later, his findings continue to be widely cited as authoritative evidence for justifying the need for additional research on these weeds. Earlier, in the 1960s, Dr. Dean Swan had also conducted similar studies with fiddleneck (Swan and Furtick, 1962). More recently, in the 2000s, Dr. Dan Ball conducted similar studies on the biology of rattail fescue (Ball et al., 2008), and his doctoral student studied competitive effects of Nuttall's and weeping alkali grasses on growth of Kentucky bluegrass (Tarasoff et al., 2009).

Mechanical in-crop tillage

Before the advent of chemical herbicides, weeds were controlled or suppressed by harrowing fields of standing wheat, or by cultivating between widely spaced rows of other crops. Harrowing the winter wheat crop in the early spring was a long-standing practice when the Sherman Station was established. The farmers believed that the harrowing served four functions: it killed weeds, it created a mulch, it reduced moisture loss from evaporation, and it stimulated additional tillering of the wheat plants. In addition, some farmers harrowed to thin the stand of wheat. Later, some farmers harrowed in the spring to partially fill the deep furrows created by deep-furrow drills, to make it easier to harvest. A long-term experiment at Moro was reported annually (Appendix 5) over a period of 41 years, from 1914 to 1954. The scientists concluded that average yields were essentially the same for winter wheat that was harrowed or not harrowed; 23.7 vs 23.4 bushels/acre, respectively. But harrowing the standing wheat crops also increased the crop's susceptibility to eyespot (strawbreaker foot rot) disease. Also, weeds that were well established weren't always killed. The practice was therefore considered to be unjustifiable in the long term, even though there was a trend for harrowing to provide some advantages during the wettest, highest-yielding crop years.

Cultivating between rows of field bean - 1920

The practice was essentially abandoned from the 1950s until the 1990s. Drs. Dan Ball, Dale Wilkins and Alex Ogg (USDA-ARS, at Pullman) re-examined in-crop tillage as a low-cost method to control downy brome without the use of full rates of recommended herbicides. They reasoned that the problem with the eyespot disease had been eliminated because modern wheat varieties with genes for resistance were now available. That disease was no longer a part of the weed-control consideration. These scientists compared the use of a mechanical flex-tine harrow and a skew treader, each alone or with a supplemental low rate of herbicide application from 1992 until 1994. The replicated trial included three timings of each tillage type and four types of herbicide treatment. The mechanical treatments reduced wheat stand density, compared to no harrowing, but actually increased the density of wheat heads. Early harrowing with application of metribuzin three days before skew treading during the spring provided the best control of downy brome. The skew treader was more effective than the flex-tine harrow. The scientists concluded that a low-cost method for effectively suppressing downy brome involved a combination of applying a low rate of metribuzin and then harrowing (preferably skew treading) the winter wheat stand only when the surface soil was dry during early spring. That combination of herbicide, tillage and soil condition reduced the downy brome density and dry weight of mature brome plants without harming the wheat stand.

Mechanical tillage of fallow

Most of the fallow tillage experiments summarized in Chapter 13 had weed control as a primary objective. In particular, the number of rod weeding of fallow fields was often dictated by the re-emergence of weeds following rain events. Studies of tillage practices to control weeds and also reduce the evaporative loss of water from fallow began when the first experiments were established in 1911 at the Sherman Station (Stephens, 1915; Stephens and Hill, 1917). Similar studies were among the first experiments established at the Pendleton Station. Investigations of those systems continue to the present day and will not be reiterated in this chapter. However, a small sampling of results from one study will be summarized as an example of the importance of this research.

Dean Swan, in his first (1955) annual report, summarized the cumulative weed-related findings from research at the King and Hill pilot farms west of Helix. Agronomists had reported the following nuances for achieving optimal efficiencies in tillage operations.

1. Rod weeder operation was affected by presence, direction and moisture content of buried mulch.
2. Duckfoot shovels ahead of the weeder rod gave more uniform penetration of the rod.
3. Center-drive rod weeders worked through heavier mulches without plugging, compared to end-drive rod weeders.
4. In years of heavy cheat grass infestation and dense wheat stands, it was necessary to skew tread after rod weeding, using a high speed (>5 MPH) in order to shake the moist soil off the matted roots to insure drying and killing. In years of light stands and light cheat grass infestation, the skew treader could be attached behind the rod weeder for effective control of cheat.

A modern rod-weeder with raised rod (left and center), and at operational 4-inch depth (right)

During the early 1990s Dr. Daniel Ball compared the efficiencies of performing tillage operations at night rather than during daylight to control Russian thistle in winter wheat at the Sherman Station. Primary tillage was with the chisel plow or cultivator. Secondary tillage was with the rod weeder. All combinations of tillage were done either at night or during the day in replicated plots. Tractor lights were on during the night-time tillage. There was a tendency for tillage during the night to have a slightly lower population of Russian thistle, compared to tillage during the day. But the season was dry, and more tests would be required for more definitive results.

Most recently, Dr. Judit Barroso and colleagues (San Martin et al., 2018) compared the weed population density, weed ground cover, and weed floral composition in winter wheat-fallow rotations in which the fallow was prepared by tillage with either a disk and rod weeder (conventional fallow), or a subsurface sweep (reduced tillage fallow). The plots in each fallow types were divided into three portions where weeds were left uncontrolled or were controlled either by using standard herbicides or manual pulling and hoeing. The most prevalent weed at the study site was downy brome. Density and area of ground covered by weeds in the control plots (no weed management) increased steadily in both types of fallow over the four-year experimental period. Weed cover was less in wheat crops produced on soil prepared with a sweep than the disk and rod weeder, mostly because the fewer numbers of weeds in the conventional fallow plots emerged earlier and grew faster than the more abundant but smaller weeds in the sweep tillage treatment. The less competitive weeds in the reduced tillage fallow resulted in slightly greater yields of winter wheat than in the conventional fallow treatment. However, the cost of herbicides was greater in the reduced tillage fallow, negating any economic advantage of the greater wheat yield in that system.

Screening herbicides in crops

Discovery of the weed-killing properties of phenoxyacetic herbicides during the early 1940s launched the 'Chemical Era of Agriculture.' In the mid- to late-1940s, when 2,4-D was first used in eastern Oregon at the 'Morning Glory Farm,' described previously, the stations also began testing sprays and dusts of various post-war formulations of 2,4-D and other herbicides. As many as 300 individual plots were treated with those compounds during 1947 to examine various herbicide formulations and concentrations for effects on weed control efficiency, wheat injury, wheat germination and wheat yield. By 1948, all of the winter wheat trials at the Pendleton and Sherman stations were sprayed with 2,4-D to control weeds; see Annual Reports listed in Appendices 5 and 6. By 1950, the use of 2,4-D to control annual weeds had become a universal practice throughout the Columbia Basin wheat growing area. Almost without exception, the spray was applied in the early spring to kill the weeds before they became well established. The scientists also conducted research to determine how weeds responded to spraying during fall or late-winter, compared to spraying in early spring.

The use of 2,4-D greatly reduced the populations and yield-reducing effects of annual weeds but the downy brome problem kept getting worse as the popularity of stubble-mulch and no-till cropping systems increased. When David Bayer, the first of eastern Oregon's trained weed scientists, was appointed for work at the Pendleton Station in 1953 he reported that "*Cheatgrass is rapidly becoming a severe weed problem in a large acreage of our dry land wheat producing area. Soil conservation practices, such as trashy fallow, is primarily the cause of the problem.*" By hand rogueing some plots, Bayer determined that downy brome reduced the yield of winter wheat by about 14 percent at Moro. He screened herbicides in the greenhouse and, the following year, he placed the most promising herbicides into field trials at Moro and Pendleton, as well as on commercial farms throughout the region. Bayer was succeeded by Dean Swan, who expanded the practice of screening large numbers of herbicides on a wide array of crops.

During the past five decades there have been innumerable new herbicide chemistries, adjuvants, formulations and combinations examined to address the weed problems in dryland agriculture. Each of the weed scientists at the Pendleton Station were important partners of manufacturers and suppliers who examined the new products and developed data required for commercial registration of the most effective products. Many hundreds of herbicide screening trials have been conducted. For instance, during 1997, Dr. Ball conducted 37 weed control experiments on crops of spring wheat, winter wheat, barley, green pea, spring canola, chickpea, fine fescue, tall fescue and Kentucky bluegrass. Ball's herbicide-screening research in 1997 included experiments in Union, Umatilla, Morrow and Sherman counties in Oregon, and Adams County in Washington.

A particular issue with herbicide research on dryland crops regards the manner in which the herbicides are applied. There are numerous possibilities and they depend upon such considerations of the crop to be produced, weed species present, stage of weed growth, tillage system practiced, timing of tillage operations, impending temperature and rainfall, soil texture, soil pH, hardness of water, and volume of spray applied. These and other factors determine whether an herbicide is applied to the soil surface before planting (pre-plant treatment), incorporated into the soil surface before planting (pre-plant soil-incorporated), applied to the surface after planting but before crop seedling emergence (pre-emerge), after crop seedlings emerge (post-emergence), after harvest (post-harvest), or just to selected patches (spot treatment). Combinations (split treatments) of these application timings are also frequently investigated.

Wheat extensively infested with downy brome and feral rye

One novel application technique used in research was the logarithmic application of herbicides to determine their toxicity to various cereals and against cheatgrass and broad-leaf weeds. Dr. Rydrych used the logarithmic application procedure to study 26 herbicide formulations or combinations as pre-plant, pre-plant soil-incorporated, or post-emergence applications in chemical and cultivated fallow systems for producing winter wheat and winter barley during 1971. The weeds targeted in Rydrych's studies included fiddleneck, purple mustard, corn cockle, cheatgrass, miner's lettuce, jagged chickweed, tumble mustard and Jacobs ladder. The concept of the logarithmic sprayer was described earlier.

Screening herbicides in fallow

Tillage was used primarily to control weeds since summer fallow was first introduced as a component of the wheat production system in the Pacific Northwest. However, tillage was usually unsuccessful for controlling deep-rooted perennial weeds such as field bindweed. Early attempts to control those weeds usually meant the use of sodium chlorate, as was discussed earlier.

Introduction of organic herbicides such as 2,4-D during the late 1940s was greatly welcomed because that innovation coincided with the strong emphasis on conservation tillage systems for fallow. It was commonly reported that weeds became more problematic in conservation tillage systems. For instance, the 1951 Annual Report for the Weed Science Program summarized findings of comparisons of tillage methods. It stated that winter wheat following black fallow prepared with a moldboard plow equipped with a jointer to bury all stubble had a 14-year average yield (since 1938) greater than for 'protected' stubble-mulch fallow prepared with a Dempster sweep plow using 30-inch sweeps that left all the crop residue on the surface; 28.5 vs 25.5 bushels/acre. Weeds were kept out of the fallow in both tillage systems by using a rotary rod weeder. By the late 1940s, all of the protected fallow plots had downy brome growing in them even though no downy brome was allowed to go to seed in the fallow. The downy brome density was high enough to reduce grain yield and was not controllable in the stubble-mulch fallow treatments.

During the 1950s, the problem with weeds in fallow was so great that attention began to turn toward the elimination of tillage in fallow. Upon his appointment in 1955, Dr. Dean Swan began screening herbicides in fallow of all types, including chemical fallow. In 1957, the Dow Chemical Company provided financial assistance for Swan's research on chemical fallow, which was the first industry-based funding received by any research program at Pendleton or Moro. That became the first time that extramural funding from industry was provided for public research at the dryland experiment stations (see Chapter 3; 'Milestones at the Pendleton Station'). Swan's first chemical summer fallow trials were on the Pendleton Station and the Hill Pilot Farm in Umatilla County, the Peck Farm in Morrow County, and the Richelderfer Farm in Sherman County.

Broadleaf weeds controlled or uncontrolled in fallow

At the Pendleton Station and the King Pilot Farm, chemical fallow plots were maintained with either Amitrole 1 or Simazine + Amitrole 2. Both herbicides provided better wheat yields than mechanical fallow with a duckfoot sweep, particularly at lower rates of nitrogen fertilizer. Yields were greater from chemical than mechanical fallow by 12.5 bushels/acre (38 percent) at 40 pound N/acre and 7.3 bushels/acre (16 percent) at 80 pound N/acre.

Swan continued to expand his search for ways to eliminate cheatgrass though the use of chemicals. In 1962, Atrazine was incorporated into the date-of-plowing plots and the chemical fallow experiments at Moro and Pendleton. Swan's goal was to test the effect of location and to compare effects of tillage timing on plots treated with the herbicide. Swan also intensified a series of tests to compare chemical fallow with cultivated fallow at other locations. His chemical fallow treatments in trials near Pilot Rock and Lexington included 18 combinations and rates of Atrazine, Amitrole, Amitrole T, Dalapon, and 2,4-D. At each location, Swan collected data on soil water storage, downy brome populations and crop yield.

By 1963, Dr. Arnold Appleby reported that "*Weed control has become the number one problem facing stubble mulch farmers*." Cheatgrass was imposing a strong influence on wheat yields. The least amount of cheatgrass in the tillage treatments occurred in plots prepared by using the moldboard plow. In chemical fallow experiments, which include tillage treatments for comparison, the least amount of cheatgrass occurred in the non-tilled plots. Much new information was generated about effects of tillage and herbicides on weed management. After that time the emphasis for controlling downy brome became heavily focused on applications of herbicides to reduce the number of tillage operations in stubble-mulch fallow systems, or to eliminate the use of cultivation by practicing strict chemical fallow practices. For instance, Dr. Daniel Ball conducted 37 weed control experiments across seven Oregon counties during 1997 and many of those trials were screenings of herbicides to quantify their ability to control weeds in cultivated or chemical fallow.

Dr. Dan Ball also examined the potential for interactions between applications of fertilizer and herbicide in imazamox-resistant wheat. No interaction was detected.

Crop rotations

Research during the 1990s involved comparisons of four cropping sequences on two farms; the Gilliland and Shaw farms. The treatments and their management were described earlier in the section on long-term off-station research sites. Downy brome was most problematic where chemical fallow was employed to maintain the 2- and 3-year rotations, and was particularly severe in the 2-year rotation. The lowest density of downy brome occurred in the treatment where hard-red spring wheat was grown annually without tillage.

Crop tolerance to herbicides

Data on the sensitivity of wheat to herbicide applications began to be collected during the first year in which a formally-trained weed scientist arrived for work at the Pendleton Station. In 1953, David Bayer established crop tolerance studies at both Moro and Pendleton. He cooperated with Dr. Charles Rohde to conduct a crop tolerance (sensitivity) study with four winter wheat varieties in which the plots were kept free of any weeds. The replicated trials consisted of 384 plots consisting of combinations of three herbicides + a check, two application rates, four wheat varieties, and three application timings. The three herbicides were 2,4-D, MCP, and 2,4-D + 2,4,5-T. Bayer and Rohde collected data on wheat growth and development, grain yield and test weight, and straw yield. They also observed that a frosty night immediately after application increased the amount of injury to wheat plants.

Crop tolerance studies have been common at the experiment stations since that time (Ball and Peterson, 2007; Rainbolt et al., 2001; Shinn et al., 1998; Swan and Rohde, 1962). Many herbicides and different crops have been studied. The crops have included winter wheat, spring wheat, spring barley, processing pea, white lupin, lentil, chickpea, hybrid poplar, many grass species, and others. In some instances, all varieties exhibited sensitivity to certain herbicides. In other instances, certain varieties were more tolerant (less sensitive) than other varieties. Sometimes the intolerance was measurable through reduced grain yield but in other instances the herbicides caused reduced plant height, reduced head counts and/or reduced tiller production without affecting grain yield or test weight. These experiments provided very important information for growers, agronomists, scientists, extensionists, and manufacturers.

Dr. Dan Ball concluded that herbicide-tolerance testing is needed for each new herbicide and on each new crop variety that might receive an application of an herbicide. Similarly, he studied and detected a wide range of herbicide tolerances to an established Conservation Reserve Program grass stand that was composed of a mixture of Kentucky bluegrass, tall fescue, Chewings fescue, sheep fescue, perennial ryegrass, Sherman big bluegrass, Sandberg bluegrass, bluebunch wheatgrass, thickspike wheatgrass and timothy.

Crop avoidance of herbicides

Atrazine was a non-selective herbicide that controlled many grass weeds and some broadleaf weeds. It was also toxic to many crop plants including wheat. It was therefore typically applied to a weed-less soil surface and then incorporated uniformly into the top few inches of soil to prevent germination of seeds and emergence of weed seedlings. During the early 1960s, while at Washington State University, Dr. Don Rydrych developed a system in which this non-selective herbicide could be used successfully in winter wheat fields. The system, named 'Inversion', was refined and became popular after Rydrych moved his research program to the Pendleton Station in 1965 (Rydrych, 1982, 1986, 1989).

Inversion was different from standard soil incorporation. Inversion did not require additional tillage operations to incorporate the herbicide into the soil. It could therefore be used in cultivated and no-till seedbeds. The practice of inversion required that atrazine be applied to the soil surface before planting. The grain drill opener is then used to clear a path in which the wheat seed was planted while the herbicide-treated soil from the furrows above the seed was moved to the area between seed rows. A packer wheel behind the seed opener compacted the soil in the furrow to reduce or eliminate recontamination of the bottom of the furrow, where the wheat seedlings would emerge. At the same time, the herbicide became incorporated into the soil between the furrows. The Inversion system created a safety band that allowed wheat seedlings to escape (avoid) injury from the application of a pre-plant non-selective herbicide. Through further studies, Rydrych expanded the Inversion system to include a number of other herbicides. During the late 1980s, Drs. Floyd Bolton and Arnold Appleby evaluated the potential to replant winter wheat into atrazine-treated wheat stands that failed for reasons such as surface crusting before seedling emergence, or winter damage. They determined that fields treated and planted in September could successfully be replanted to winter wheat in November, and to spring wheat during early spring (Bolton, 1989). Also during the 1990s, Dr. Daniel Ball determined that the Inversion system did not work in cloddy seedbeds. He found that pre-plant surface applications of atrazine, metribuzin and chlorsulfuron into cloddy seedbeds, each individually or in combinations, resulted in poor wheat stands and high densities of downy brome.

Another form of crop avoidance was also studied by Dr. Rydrych. He examined pre-emergence and post-emergence applications of metribuzin for controlling downy brome in winter wheat. The herbicide controlled the downy brome but also injured the winter wheat. He identified a way to successfully overcome that problem. Wheat injury was greatly reduced or eliminated where activated carbon was applied to a 2-inch band of soil over the seed row prior to seedling emergence, and the herbicide was then applied after seedling emergence (Rydrych, 1985). Pre-emergence applications of the herbicide were not effectively neutralized by the safening treatment with activated carbon.

Herbicide-resistant crops

The development and registration of wheat and canola varieties that were intentionally bred for resistance to herbicides required close collaboration between crop breeders and weed scientists. Dr. Ball was the weed scientist at Pendleton when the first of these new wheat varieties were being developed. He was a key member of the research team that released Oregon's versions of IMI-wheat, an acronym referring to varieties that were resistant to the imazamox herbicide. These varieties were also known as Clearfield varieties. This technology provided a huge advance in the ability of farmers to control weeds such as downy brome and jointed goatgrass. Crops of an IMI-wheat variety could be sprayed with imazamox to provide total control of those weeds (Ball et al., 1999a, 1999b; Ball and Peterson, 2007). Regular wheat varieties, without the gene for resistance to imazamox, were killed if they happened to be sprayed with that herbicide. The weed scientists needed to determine the tolerances of different IMI-wheat selections and also determine the sensitivity of other varieties and crop species to any residual imazamox that might remain in the soil (Ball et al., 2003). That technology became registered and is widely used in the wheat industry at the present time.

For a short time, Ball also conducted tolerance studies with spring wheat that was bred for resistance to glyphosate. He also studied methods to eradicate volunteer plants of overwintered glyphosate-resistant spring wheat, as well as the relative efficiencies of different formulations of glyphosate. That technology was never registered for wheat and that line of research was therefore brief. However, glyphosate-resistant canola was registered for commercial production. Ball therefore also screened Roundup Ready canola varieties and production systems.

Herbicide resistance in weeds

Repeated applications of herbicides have led to selections of weed biotypes having resistance or tolerance to various herbicides. There are many such instances across the world and a growing number of herbicide-resistant weeds in Oregon. In 1993, Dr. Daniel Ball identified populations of Kochia and Russian thistle that were resistant to sulfonylurea herbicides at eight locations distributed across northeast and north-central Oregon (Ball and Walenta, 1994). He suspected that the same may be true for prickly lettuce. Later, other weeds in Oregon also were found to be resistant to additional herbicides. They included downy brome (Ball et al., 2007) and jointed goatgrass (Hanson et al., 2002). In 2016, Dr. Judit Barroso determined that populations of Russian thistle had also become resistant to glyphosate (Barroso et al., 2018). These findings altered the way in which fields are managed. Some

Downy brome susceptible (left) or resistant (right) to pyroxsulam herbicide; 0 – 4x normal rate

Russian thistle susceptible (left) or resistant to glyphosate herbicide; 0 – 4x normal rate

growers with herbicide-resistant weed populations have reverted from chemical fallow practices back to mechanical tillage, whereas other growers have applied other types of herbicides that may be more costly or pose a greater health risk to the farmer's that apply them.

The potential for development of weeds with resistance to herbicides is particularly pronounced with the repeated production of wheat varieties that were bred to be resistant to a particular herbicide. This is the situation for the IMI-wheat varieties described in the previous section. One of Dr. Dan Ball's graduate students, Dr. Curtis Rainbolt, determined through experimentation how many applications of imazamox herbicide would be necessary before imazamox-resistant weed seeds might begin to become established (Rainbolt et al., 2004a, 2004b). Those studies showed that resistance to that herbicide could arise quite readily in populations of downy brome, jointed goatgrass and wild oat. Studies such as Rainbolt's helped the manufacturer establish agronomic practice guidelines to which the growers who used that technology had to agree before they could buy seeds of imazamox-resistant wheat varieties. The careful use of such regulations has slowed the development of herbicide resistance in weeds in eastern Oregon.

Herbicide persistence in soil

Residual concentrations of herbicides can become critically important in many cropping systems. This is particularly true in crop rotations where an herbicide applied to one crop may, if not decomposed, affect emergence and growth of a subsequent crop. This may also become an issue in situations where winter wheat must be replanted because the first planting, which may have been treated with an herbicide, fails to emerge properly due to poor soil moisture or surface crusting. Similar issues arise for winter wheat that succumbs to low winter temperatures and fields must be replanted with spring wheat or another spring crop.

Drs. Rydrych and Ball conducted many studies to evaluate the potential for herbicide carry-over from one crop to the next (see annual reports; Appendix 6). For instance, one study determined if applications in green peas had any adverse influence on growth and yield of winter wheat. Other studies were to examine the efficiency of 16 pre-emergent herbicides applied to standing winter wheat stubble in chemical fallow fields to control grass weeds. Populations of volunteer wheat and downy brome were evaluated during late spring and, in late May, the land was chisel plowed, rod weeded, and planted to winter wheat to evaluate any carry-over injury from the fall-applied herbicide treatments.

Ball also examined the carry-over of sulfonylurea herbicides applied to winter wheat into subsequent plantings of rotational crops such as fall canola, spring canola, spring mustard, green pea, onion, potato, sweet corn, mint, sugar beet, wheat, and grass-seed crops. These and related studies were conducted at sites across several Oregon counties. It was common to detect some phytotoxicity in fall-planted crops but not in spring-planted crops. Similar studies were conducted with the imazamox herbicides in cultivated and direct-seeded fields.

In 2004, Dr. Ball also evaluated the tolerance of grape plantings to residual carry-over of the post-emergent grass-control herbicide imazethapyr (Pursuit).

Persistent herbicides have been used in attempts to eradicate deep-rooted perennial weeds such as field bindweed. In 1962, Dr. Arnold Appleby reported from the Pendleton Station that seven of the nine field bindweed plots treated with 2,3,6-trichlorobenzoic acid (TBA) in 1959 were still completely free of the weed but the highest application rates were still reducing wheat yields by about 50 to 65 percent in the treated areas. Similar observations were common where pichloram (Tordon) was used to kill patches of field bindweed.

Herbicide drift

Weed scientists who conduct applied research are always in high demand for extension-related activities. Many of the interactions with growers lead to fruitful topics for further research. There are innumerable examples of that process, which will be exemplified by just one line of research by Dr. Ball. During the early 1990s, many fields of green peas began to show symptoms of abnormal growth. In many cases there was a gradient in which the symptom was most severe near one of the field boundaries, a diminishing effect as one walked further into the field, and the absence of symptoms at some distance into the field. On-site investigations pointed to the likelihood that the damage was associated with drift of an herbicide, but the exact cause needed to be determined to meet the requirements of insurance settlements or litigation.

Dr. Ball established studies of 'simulated drift' for different rates of thifensulfuron + tribenuron applied to fields of green pea, spring canola and fall canola. Eleven rates of herbicide concentration were evaluated. Ball described the expression and the time delay until the onset of phytotoxic symptoms. Numerous symptoms were described at all stages of plant growth, from seedlings to onset of blossoming. Ball measured seed yields and the germinability of seed produced under each condition. Since canola is a plant with a semi-determinant flowering habit, the simulated drift caused very significant reductions in seed yield. Any drift at all caused immediate reduction in yield in canola. At the highest rates of simulated drift, the canola did not produce any seed at all, compared to a yield of 2,250 pound/acre for the untreated control in fall canola, and 840 pound/acre for the untreated control in spring canola. Since pea is a plant with an indeterminate growth habit, the simulated drift was not as harmful as on canola. With pea, the highest application rates caused severe symptoms but the seed yield was reduced by 60 percent, which was critical but far less than for canola. Ball also became involved as an expert spokesperson for drift-related issues for cherry orchards, grape vineyards and other crops being produced in lands near wheat-production fields (Ball et al., 2014).

During the 2000s, Dr. Donald Wysocki provided technical support and guidance for observations of widespread drifts of glyphosate over wheat fields after being applied to nearby fallow fields. Wysocki examined locations and patterns of symptoms with respect to herbicide application dates and the weather at the times of application.

Stubble burning

In a study on the long-term residue management experiment at the Pendleton Station, Paul Rasmussen found that the number of downy brome seedlings were much greater where stubble was not burned than where stubble was burned during the spring (Rasmussen, 1995). He had shown earlier that burning stubble during the spring increased the temperature at the soil surface but had no effect on soil temperature one inch below the surface (Rasmussen et al., 1986). Also, the temperature at the surface was very transitory, it returned to the pre-burn temperature within three minutes after ignition, and was highly variable across the area, particularly where the burn was not complete.

Dr. Ball also examined the downy brome seed population in treatments of the long-term residue management experiment at Pendleton (Ball et al., 1996 SR). He determined that there were 33 viable downy brome seeds/ft^2 in winter wheat stubble of a treatment that was not burned, and was reduced to 9 viable seeds/ft^2 where stubble was burned during the autumn, and 26 viable seeds/ft^2 where stubble was burned during the spring. In a more recent study of that experiment, Ball determined that the population of live downy brome seeds in the top two inches of soil was much greater where stubble remained unburned (167 viable seed/ft^2) than where stubble was burned during the spring (fewer than 20 viable seed/ ft^2).

Biological control

Very little research at Pendleton has focused on biological control practices for weeds in Oregon. Drs. Rydrych and Ball collaborated with county weed control districts that were monitoring the effectiveness of parasitic insects which were released to suppress yellow star thistle on rangeland.

Two biological control experiments investigated applications of a bacterium purportedly helpful for reducing populations of downy brome (Kennedy et al., 1991). Drs. Ball, Alex Ogg and Ann Kennedy established an experiment at the Pendleton Station in 1992 to examine various rates and timings of preplant and post-emergence applications of the bacterium. None of the treatments provided acceptable control of downy brome. Dr. Judit Barroso reexamined a commercialized formulation of the same bacterium at Pendleton from 2016 until 2018. She examined applications of the bacterium with or without a companion treatment of Axiom (flufenacet) herbicide. Barroso also detected no benefit from applications of the bacterium. In contrast, the chemical herbicide successfully eliminated all of the downy brome in her experiment.

Several scientists at the Pendleton Station have examined toxic leachates from various plant species to determine they could be used to control weeds in wheat or peas. Decomposition products of numerous plant species are known to be capable of reducing the germination of other plant species. This phenomenon is called allelopathy. If successful, this practice could be of particular importance for producing organic crops. Dr. Ball found that applications of residual material (seed meal) after extracting the oils of Brassica seeds could suppress germination of weed seeds in spring wheat and peas. Likewise, Dr. Stephen Machado tested various plants for their ability to suppress germination of downy brome. He grew plants to the flowering stage in a greenhouse and then separated the shoots and roots. The plant materials were dried and ground, and then suspended in water. The water extract was added to sand, which was then planted with seeds of downy brome and spring wheat. Extracts from most plant species inhibited germination of seeds of both downy brome and wheat. Extracts from broadleaf plants were more inhibitory than extracts from cereal plants, and extracts from shoots were generally more inhibitory than root extracts. Extracts from meadowfoam seed meal, radish, yard-long bean, blue spruce and pine greatly or completely inhibited the germination of downy brome seed. However, meadowfoam and radish also severely inhibited germination of wheat seed as well as growth of wheat plants. Nevertheless, these studies demonstrated that some plants have the potential to be used for controlling weeds in organic cropping systems.

Killing weeds with electricity

An 'electrovator machine' to control deep-rooted perennial weeds such as Canada thistle and field bindweed by use of electricity was tested at the Crow Pilot Farm during the 1950s. The machine generated a very high current (12,000 to 15,000 volts) and distributed that current to a crossbar carrying short mesh chains that were dragged in contact with the soil ahead of the tractor. The manufacturer recommended treating the morning glory at least five times each year. The electric current supposedly passed down into the roots of the morning glory, and the five treatments were thought to be capable of completely eradicating the weed. The machine was also touted for controlling Canada thistle, Russian knapweed, whitetop and blue flowering lettuce. Tests on the Crow Farm were on three-quarter acre patches of Canada thistle and a 70-foot diameter patch of morning glory. Two runs with the machine were made in 1951. The Canada thistle disappeared and didn't grow back in the fall. Only three thistle plants appeared in the following wheat crop. In contrast, the morning glory came back with vigor after the two treatments. Three more electric treatments were made in 1952 and the morning glory plants were definitely weakened. The morning glory weed patch was cultivated with a sweep plow after the third treatment. As a comparison, another acre of scattered morning glory patches were treated seven times during 1952, and then the area was swept, spring toothed, and planted to winter wheat. In the 1954 Pendleton Station Weed Management Annual Report, weed scientist David Bayer concluded that the electrovator was no better than application of 2,4-D for controlling morning glory and Russian knapweed in Umatilla County. This finding appears to have also been common in other regions. In a review of literature pertaining to weed control, Timmons (2005) stated that "*Several versions of an "electrovator" for control of deep-rooted perennial weeds by electricity were promoted during the 1940's with sporadic profits by promoters but little success in weed control*." Interestingly, that technology was resurrected in 2019, with advertisements from a manufacturer appearing in several industry magazines.

Electrovator being used at the Crow Pilot Farm

Destruction of weed seeds during wheat harvest

There is an increasing importance of weeds that have become resistant to herbicide applications. This has caused a resurgence in efforts to manage weed populations by using non-chemical methods. Many weeds shed their seed before wheat is harvested. However, some weeds retain all or some of their seeds even until the time wheat is harvested. It has been of recent interest to try to destroy or remove seeds of those weeds that retain at least some seed at the time of wheat harvest. Viable weed seeds are therefore prevented from falling to the soil surface, which essentially allows them to become 're-seeded.' If wheat is harvested in the normal manner, most of the weed seeds remaining in the aerial canopy are ejected from the wheat combine with the chaff. On today's combines, the chaff is spread in a swath nearly as wide as the combine header. Viable seeds of weeds and wheat therefore become widely dispersed in stubble.

Collecting chaff to count weed seeds

Direct baling of chaff and weed seeds

Removing weed seeds by using a 'chaff cart' to collect chaff and weed seeds

Various types of equipment are being introduced to destroy the weed seeds so they cannot germinate, thereby reducing the weed density over time (Lyon et al., 2019). The approaches include 1) attach a 'chaff cart' to the combine to collect and remove the chaff and weed seeds, 2) attach a baler to the combine to bale and remove the chaff and weed seeds, 3) install an impact mill inside the combine to destroy seeds which are then non-viable and can be spread with the chaff, an 4) concentrate the chaff into narrow rows behind the combine or in the combine wheel rows. The latter technique concentrates the weed seed so they have poorer germination or plant vigor, or grow in such narrow bands that they do not compete effectively with the yield of the next wheat crop. Alternatively, the narrow bands can be burned or grazed by animals.

Dr. Judit Barroso has actively participated in research to examine the efficiency and economic benefits of the seed-destruct and seed-removal technologies. She found that Her studies have included the weeds downy brome, Italian ryegrass, rattail fescue and blue mustard had an average seed retention of less than 50 percent at the time of wheat harvest. Also, remaining rattail fescue and blue mustard seeds were located less than 12 inches from the soil surface. Those four weeds were therefore unlikely to be good candidates for application of seed destruction or seed removal. In contrast, more than 50 percent of the seeds of cereal rye and tumble mustard were retained at harvest, and were positioned above 12-inch height. It was hypothesized that those weeds may be amenable to control by these technologies. However, in research over two years at three farms, these weeds were not reduced by chaff collection. The best treatment was the direct-bale system, and it removed less than 11 percent of the seeds of tumble mustard. Also, the removal of chaff caused a reduction in soil moisture in the top foot of soil. Removing weed seeds and chaff was considered either non-effective or non-profitable in low rainfall regions.

Influences of other agronomic practices

The application of fertilizer is well known for its ability to modify the density of winter annual grass weeds such as downy brome (Rasmussen, 1995). This phenomenon was quantified by Ball et al. (1996), who evaluated effects of nitrogen fertilizer application timing on densities of downy brome. Compared to nitrogen applications during the summer fallow period before planting winter wheat, the biomass of downy brome became greater when nitrogen was applied at the time of planting or was top-dressed onto the winter wheat stand during early spring. The latter applications increased wheat yields when downy brome was controlled with a herbicide but that benefit was reduced without protection of the crop by applying a herbicide.

Ball et al. (1998) then evaluated the number of downy brome seeds left in soil by the different fertilizer treatments. They determined that the seedbank was greatly increased where winter wheat had received 80 pound N/acre (511 viable seed/ft^2 to a 2-inch depth) than when no nitrogen fertilizer was applied (33 viable seeds/ft^2). In the no-nitrogen treatment, the number of viable seeds was diminished only by a small amount when the stubble was burned during the fall (9 viable seeds/ft^2) or spring (26 viable seeds/ft^2). Ball expanded that line of investigation. During the following year he determined that the number of residual live downy brome seed was much greater where winter wheat received 80 pound N/acre (167 viable seed/ft^2 to a 2-inch depth) or 40 pound N/acre (149 seed/ft^2) compared to no nitrogen fertilizer (16 seeds/ft^2). Much lower downy brome populations occurred when stubble from these fertilizer treatments was burned during the spring or fall; 19, 17 or 19 viable seeds/ft^2, respectively.

Dan Ball also studied the potential for an interaction between the application of triallate (Far-Go) herbicide and the use of protectant fungicides as seed treatments for winter wheat. The seed protectants improved wheat stand density but neither the seed treatments nor the triallate affected plant height, head count, grain yield, or test weight.

Deterioration of Native Grass Stands by Weeds

One of the research objectives of research on forage grasses and legumes (see Chapter 8) at the Sherman and Pendleton stations was to evaluate the persistence of pasture species. As expected, the density of less-adapted species became thinner over time. It was common for weeds to replace the desired grasses and legumes as the stands deteriorated. However, it was not determined whether weed competition caused the stand to deteriorate, as compared to the competitive weeds simply being able to fill the vacancies left by death of the desired grasses. In any case, data collected during the forage research was extremely valuable to those interested in planting grass species that had the greatest prospect for successful establishment and persistence. For example, in 1944, Merrill Oveson reported on the attrition over the years of grass plantings made from 1935 to 1937. He reported that the surviving species were mostly limited to those already known to be native to the Pacific Northwest. He considered heavy weed competition to be a key factor leading to the deterioration of those strains and varieties that were less adapted to the local environment. Data was collected to report seed and forage yields from each plot, and also the percentage of each plot occupied by downy brome. The best adapted varieties had very little downy brome and the more poorly adapted varieties were very thin and were dominated by downy brome. Oveson concluded that

"*It is questionable that even with careful controlled grazing the native grasses will be able to establish new stands where the cheat has become well established*."

Spot Spraying of Individual Weeds

Dr. Ball examined the efficiency of an emerging technology that had the potential to greatly reduce the volume of herbicide applied over a field, and thereby create a great monetary savings as well as ecological benefits. He evaluated an early version of the WeedSeeker® sprayer technology, in which a light-activated sensor is mounted on each spray nozzle to determine when or if that nozzle is to be on or off (Ball and Bennett, 2008; Riar et al., 2011). That early testing of the technology was then applied to comparisons of weed management systems that included six treatments; conventional plow-based tillage followed by rod weeding, sweep-tillage followed by rod weeding, chemical fallow, each of which included herbicides applied as a uniform spray or as a light-activated individual nozzle spray (Riar et al., 2010). The light-activated spray produced equivalent results with the uniform spray, and also reduced the volume of herbicide applied by 45 to 70 percent. Winter wheat yields were greatest, by 21 percent, in the combined treatment of sweep tillage and light-activated spray technology. The authors concluded that that combination of practices had the potential to replace more tillage-intensive fallow systems in the dryland region.

Since that time, detector technology has become refined to the point of detecting weeds that are less than an inch in diameter, and activate the necessary spray nozzle in a timely manner while the equipment is travelling across the field at a speed up to five miles per hour. These innovations are now providing a great savings in application expense and ecological benefits by reducing the volume of herbicide by as much as 90 percent.

Site-Specific Mapping of Weeds

In Chapter 14 it was stated that sensing technologies were currently being studied at Pendleton to create maps of variable grain yield, grain protein, straw yield, and nitrogen or water stress as the combine was cutting grain. With regard to weed management, it was also stated that the multi-sensing technology was being enhanced by incorporating an optical sensor to detect green plant material within the grain stream, denoting the presence of green weeds in the area being harvested. This technology was found to be useful for mapping the distribution of weeds such as kochia, Russian thistle and prickly lettuce (Barroso et al., 2017; San Martin et al., 2016). The goal of such research is to develop decision thresholds as a factor in determining if herbicides can be applied in site-specific management programs.

***References*:**

Annual Reports from the Sherman and Pendleton Stations (Appendices 5 and 6)

Letters sent to or from the Station Superintendents

Ball, D. A 1992. Weed seedbank response to tillage, herbicides, and crop rotation sequence. Weed Science 40:654-659.

D. A. Ball, and L. Bennett. 2008. Light-activated sensor sprayer for reduced herbicide use in no-till fallow. Oregon Agricultural Experiment Station Special Report 1083:15-19.

Ball, D. A., S. M. Frost, and L. H. Bennett. 2007. ACCase-inhibitor herbicide resistance in downy brome (*Bromus tectorum*) in Oregon. Weed Science 55:91-94.

Ball, D. A., S. M. Frost, and A. I. Gitelman. 2004. Predicting timing of downy brome (*Bromus tectorum*) seed production using growing degree-days. Weed Science 52:518- 524.

Ball, D. A., B. Klepper, and D. J. Rydrych. 1995. Comparative above-ground development rates for several annual grass weeds and cereal grains. Weed Science 43:410-416.

Ball, D. A., A. G. Ogg, Jr., and F. L. Young. 1999a. Selective control of jointed goatgrass (*Aegilops cylindrica*) with imazamox in herbicide-resistant wheat. Weed Technology 13:77-82.

Ball, D. A., R. Parker, J. Colquhoun, and I. Dami. 2014. Preventing Herbicide Drift and Injury to Grapes. Oregon State University Extension Publication EM 8860. 8 pages.

Ball, D. A., and C. J. Peterson. 2007. Herbicide tolerance in imidazolinone-resistant wheat for weed management in the Pacific Northwest U.S.A. Pages 243-250. In: Wheat Production in Stressed Environments. (H. T. Buck, J. E. Nisi, and N. Salomón, editors). Springer. The Netherlands. 794 pages.

Ball, D., D. Rydrych, and B. Klepper. 1993. Relationship between growing degree days and development rate for jointed goatgrass and several other winter annual grasses and cereals. Pages 60-63. In: Jointed Goatgrass: A Threat to U.S. Wheat (P. Westra and R. Anderson, editors). Proceedings of the Jointed Goatgrass Symposium, Denver, CO.

Ball, D. A., and D. L. Walenta. 1994. Sulfonylurea herbicide resistance in the Columbia Basin of northeastern Oregon. Oregon Agricultural Experiment Station Special Report 933:45-47.

Ball, D. A., D. L. Walenta, and P. E. Rasmussen. 1998. Impact of nitrogen fertilization and stubble burning on the downy brome seedbank in a winter wheat- fallow rotation. Journal of Production Agriculture 11:342-344.

Ball, D. A., D. J. Wysocki, and T. G. Chastain. 1996. Nitrogen application timing effects on downy brome and winter wheat growth and yield. Weed Technology 10:305-310.

Ball, D. A, J. P. Yenish and T. Alby III. 2003. Effect of imazamox soil persistence on dryland rotational crops. Weed Technology 17:161-165.

Ball, D. A., F. L. Young, and A. G. Ogg, Jr. 1999b. Selective control of jointed goatgrass with imazamox in herbicide-resistant wheat. Weed Technology 13:77-82.

Barroso, J., J. A. Gourlie, L. K. Lutcher, L. Mingyang, and C. Mallory-Smith. 2018. Identification of glyphosate resistance in *Salsola tragus* in northeastern Oregon. Pest Management Science 74:1089-1093.

Barroso, J., J. D. McCallum, and D. S. Long. 2017. Identifying weed infestations with optical data at harvest. Sensors 17:1-17.

Barroso, J., Z. J. Miller, E. A. Lehnhoff, P. Hatfield, and F. D. Menalled. 2015. Impacts of cropping system and management practices on the assembly of weed communities. Weed Research 55:426-435.

Bolton, F. E. 1989. Atrazine use in winter cereals under three tillage systems. Oregon Agricultural Experiment Station Special Report 840:62-63.

Hanson, D. E., D. A. Ball, and C. A. Mallory-Smith. 2002. Herbicide resistance in jointed goatgrass (*Aegilops cylindrica*): Simulated responses to agronomic practices. Weed Technology 16:156-163.

Harris, L. E., and G. A. Mitchell. 1944. Control of Wild Morning Glory or Bindweed by Cultural Methods. Oregon State College Agri. Exp. Station Circular of Information 336. 14 pages.

Kennedy, A. C., L. F. Elliott, F. L. Young, and C. L. Douglas, Jr. 1991. Rhizobacteria suppressive to the weed downy brome. Soil Science Society of America Journal 55:722-727.

Lyon, D. J., M. J. Walsh, J. Barroso, J. M. Campbell, and A. G. Hulting. 2019. Harvest weed seed control: Applications for PNW Wheat Production Systems. Pacific Northwest Extension Bulletin 730. Washington State University Extension Service, Pullman. 12 pages.

Machado, S. 2007. Allelopathic potential of various plant species on downy brome: Implications for weed control in wheat production. Agronomy Journal 99:127-132.

McGregor, A. C. 1982. *Counting Sheep: From open range to agribusiness on the Columbia Plateau*. University of Washington Press, Seattle. 482 pages.

Rainbolt, C., D. A. Ball, D. Thill, J. Yenish. 2004a. Management Strategies for Preventing Herbicide-Resistant Grass Weeds in Clearfield Wheat Systems. Pacific Northwest Extension Publication PNW 572. 8 pages.

Rainbolt, D. R., D. C. Thill, and D. A. Ball. 2001. Response of rotational crops to BAY MKH 6561. Weed Technology 15:365-374.

Rainbolt, C. R., D. C. Thill, J. Yenish, and D. A. Ball. 2004b. Herbicide-resistant grass weed development in imidazolinone-resistant wheat: Weed biology and herbicide rotation. Weed Technology 18:860-868.

Rasmussen, P. E. 1995. Effects of fertilizer and stubble burning on downy brome competition in winter wheat. Communications in Soil Science and Plant Analysis 26:951-960.

Rasmussen, P. E., R. W. Rickman, and C. L. Douglas, Jr. 1986. Air and soil temperatures during spring burning of standing wheat stubble. Agronomy Journal 78:261-263.

Riar, D. S., D. A. Ball, J. P. Yenish, and I. C. Burke. 2011. Light-activated, sensor-controlled sprayer provides effective postemergence control of broadleaf weeds in fallow. Weed Technology 25:447-453.

Riar, D. S., D. A. Ball, J. P. Yenish, S. B. Wuest, and M. K. Corp. 2010. Comparison of fallow tillage methods in the intermediate rainfall inland Pacific Northwest. Agronomy Journal 102:1664-1673.

Rydrych, D. J. 1974. Competition between winter wheat and downy brome. Weed Science 22:211-214.

Rydrych, D. J. 1981. Corn cockle (*Agrostemma githago*) competition in winter wheat (*Triticum aestivum*). Weed Science 29:360-363.

Rydrych, D.J. 1982. "Inversion", a new technique for downy brome control. Oregon Agricultural Experiment Station Special Report 661:18-20.

Rydrych, D. J. 1985. Inactivation of metribuzin in winter wheat by activated carbon. Weed Science 33:229-232.

Rydrych, D.J. 1986. A breakthrough for selective cheatgrass control in winter wheat. Oregon Agricultural Experiment Station Special Report 776:37-39.

Rydrych, D.J. 1989. A history of "Inversion" - A successful technique for weedy brome control in cereals. Oregon Agricultural Experiment Station Special Report 840:64-67.

Rydrych, D. J., and T. J. Muzik. 1968. Downy brome competition and control in dryland wheat. Agronomy Journal 60:279-280.

San Martin C., D. S. Long, J. A. Gourlie, and J. Barroso. 2018. Suppression of downy brome by reduced tillage fallow in dryland winter wheat. PLoS One 13(9):1-17.

San Martin, C., D. Lyon, M. Thorne, and J. Barroso. 2020. Seed retention of major weed species at harvest in the PNW. PLoS One XX: XX-XX (submitted).

Shinn, S. L., D. C. Thill, W. J. Price, and D. A. Ball. 1998. Response of downy brome and rotational crops to MON 37500. Weed Technology 12:690-698.

Smiley, R. W., K. Merrifield, L.-M. Patterson, R. G. Whittaker, J. A. Gourlie, and S. A. Easley. 2004b. Nematodes in dryland field crops in the semiarid Pacific Northwest USA. Journal of Nematology 36:54-68.

Stephens, D. E. 1915. Report of the Eastern Oregon Dry-Farming Branch Experiment Station, Moro, Oregon: 1913-14. Oregon Agricultural College Experiment Station. (no number assigned). 42 pages.

Stephens, D. E., and C. E. Hill. 1917. Dry Farming Investigations at the Sherman County Branch Experiment Station. Agricultural Experiment Station Bulletin 144, Oregon Agricultural College, Corvallis. 47 pages.

Swan, D. G., and W. R. Furtick, 1962. Competition of fiddleneck with wheat. Weeds 10:121-123.

Swan, D. G., and C. R. Rohde, 1962. Effect of 2,4-D on three winter wheat varieties grown in Oregon. Crop Science 2:179-180.

Tarasoff, C. S, D. A. Ball, and C. A. Mallory-Smith. 2007a. Afterripening requirements and optimal germination temperatures for Nuttall's alkali grass and weeping alkaligrass. Weed Science 55:36-40.

Tarasoff, C. S., D. A. Ball, and C. Mallory-Smith. 2007b. Extreme ionic and temperature effects on germination of weeping alkaligrass, Nuttall’s alkaligrass and Kentucky bluegrass. Weed Science 55:305–310.

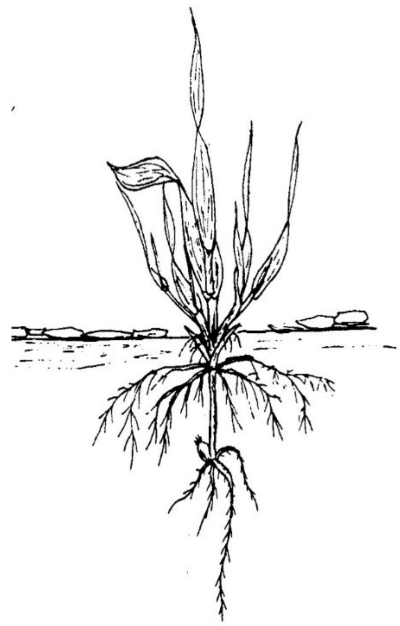
Tarasoff, C. S., C. Mallory-Smith, and D. A. Ball. 2009. Competitive effects of Nuttall’s and weeping alkaligrass in Kentucky bluegrass. Northwest Science 83:325-333.

Timmons, F. L. 2005. A history of weed control in the United States and Canada. Weed Science 53:748-761.

Yenish, J. P., D. A. Ball, and R. Schirman. 2009. Integrated Management of Jointed Goatgrass in the Pacific Northwest. Washington State University Extension Bulletin EB2042. 16 pages.

Young, F. L., J. P. Yenish, D. L. Walenta, and D. A. Ball. 2003a. Spring germinating jointed goatgrass produces viable spikelets in spring seeded wheat. Weed Science 51:379-385.

Young, F. L., J. P. Yenish, D. L. Walenta, D. A. Ball, and J. R. Alldrege. 2003b. Spring-germinating jointed goatgrass produces viable spikelets in spring seeded wheat. Weed Science 51:379-385.



Chapter 22 - Insect Pests

The Sherman and Pendleton Stations have never employed a formally-trained entomologist. However, several scientists have evaluated insects that affected their research. With two exceptions, research conducted by station scientists was opportunistic rather than targeted. The exception to that approach occurred for Russian wheat aphid and Hessian fly, both of which became targets of specific studies. In other instances, the scientists took notes on damage caused by an insect but did not establish a research trial with the specific intent to study that insect. Several such studies led to collaborations between the local scientists and entomologists located at Corvallis and Hermiston, OR, Pullman and Prosser, WA, Moscow, ID, Manhattan, KS, and Washington, D.C. Examples of specific research on insect pests are discussed.

Wireworm

The wireworm was the first insect pest mentioned in documentation from the Sherman Station. Harry Umberger received a letter from James Hyslop, USDA Bureau of Entomology, Pullman, Washington, dated May 26, 1910. In that letter Hyslop stated "*I am inferred … that wireworms are doing considerable damage to wheat in your part of the country. Would it be possible for you to obtain some of these wireworms and send them to me in a baking-powder tin or similar package. I am making a special study of wireworms in the north-west*." Umberger responded on June 1, 1910, stating "*I am, this morning, sending you a package containing a number of these worms. They are probably the cause of more damage to grain in these parts than all other causes put together*." The Station's Annual Report for 1911 indicated that "*The weather favored an unusually severe damage by wireworms, which caused great damage to spring crops*." During the following five years, there were many letters about this issue exchanged between David Stephens and A. C. Lovett (an entomologist at Oregon State College), who directed Stephens to recommend that farmers change to a four-year rotation including several years of legumes, and to plow summer fallow during the early summer. Recognizing that Lovett's guidance was totally impractical for the region, Stephens ignored the Oregon State College recommendations and communicated recommendations from Professor Hyslop, at Pullman. Stephens exchanged many letters with farmers from eastern Oregon and south-central Washington, regarding concerns over wireworms and other insect pests. Over the years, personnel at the Sherman Station contributed to Hyslop's research to map regions of the inland northwest where the infestations became most damaging, and also contributed to the knowledge regarding practices that could minimize the damage. Later, a bulletin was published to describe the biology and control of wireworm in dryland wheat fields east of the Cascade Mountains (Lane, 1931).

During 1929, it was stated that "*Spring crops emerged well but many spring stands were ravished by wireworms, making comparisons among treatments very difficult* … [and] *yields were the poorest since the Station was established*." In 1940, the early-maturing varieties of wheat were not as badly affected by wireworm as the late-maturing varieties. Moreover, knot weed became especially well established where the wireworm had thinned stands of the late-maturing varieties. During the 1940s the wireworm was mentioned during several more years. In 1948, it was stated that "*Wireworms that had caused considerable crop damage during previous years were controlled this year by application of 'Shell D.D.' to the summer fallow*." Likewise, in 1950 the Annual Report indicated that "*Good data was obtained for all experiments with spring barley at Moro and each of the off-station locations. There was no wire-worm damage because the nursery ground was treated with D-D-T in 1949*."


Wireworm damage to plants in 4-row drill strips that were either treated with a nematicide/insecticide, or were not treated.

Dr. Richard Smiley abandoned a field experiment east of Heppner during 2008. Two 1-acre experiments were planted into a notill field to screen varieties for tolerance to root-lesion nematode. The varieties were planted into paired drill rows which differed in that the varieties in one drill row were treated with an experimental nematicide and the other drill row was left without treatment to simulate 'what the farmer would have seen.' One block was planted to winter wheat and the other was planted to spring wheat and barley. The field around the experiments had been planted to winter wheat. Stands in the winter wheat trial and in the field were very good. Stands in the spring wheat trial emerged very well in the alternate drill rows into which the nematicide had been applied at the time of planting. However, in the non-treated control drill rows there were few if any plants of all varieties of spring wheat and spring barley. An aerial photograph depicted a field of wheat with 6-foot-wide parallel strips of bare soil across the 1-acre spring grain block. Wireworms had killed nearly all plants of spring wheat and barley in the experiment, and had done the same in an adjacent field of spring wheat. Soon thereafter, Washington State University developed an extensive research effort on these insects, including the creation of an endowed chair for that research.

Aphids

In early reports from the two dryland stations in Oregon, it was occasionally stated that aphids (sometimes called plant lice) caused some damage to the plants. This was particularly true for forage and food legume crops such as pea. During the 1990s the University of Idaho installed aphid traps at both stations and at numerous other locations across the Pacific Northwest. A suction applied to the top of 30-foot high tubes pulled aphids onto a sticky trap which could be collected and examined at regular intervals. Scientists in Idaho identified and quantified the aphids that were collected.

The Russian wheat aphid was first identified in North America during 1980. It quickly spread northward and westward from Mexico and was first identified in Umatilla and Morrow counties during the fall of 1987. In the Pacific Northwest, this new species of aphid completely ruined wheat crops in some fields and caused severe yield losses in many other fields. Dr. Pamela Zwer, wheat breeder at the Pendleton Station, established an intensive program to breed wheat for resistance to the Russian wheat aphid. Aphids were reared on susceptible seedlings grown inside screened cages within a greenhouse. Nearly one thousand wheat varieties and breeding lines were evaluated by planting 12 seeds of each entry into a wooden flat filled with potting soil. Plants of a susceptible barley variety and a resistant oat variety were also sown into each flat for comparison with the wheat varieties. Three to five aphids were transferred onto the soil at the base of each plant when the test varieties were in the 3-leaf seedling stage. The aphids immediately migrated into the first leaf whorl of each seedling. The infested plants were evaluated after three weeks. None of the test plants were immune to the aphid. Two percent of the entries showed chlorotic spots but no leaf folding. All other entries contained the typical symptoms of attack by Russian wheat aphid, including rolled leaves, extensive chlorosis, and mid-veinal striping. Some plants were killed, as was also observed in commercial fields. Dr. Zwer sent the most tolerant (or resistant) lines to scientists at Colorado State University for further evaluation in their studies of the genetic inheritance of resistance to this aphid. Zwer also imported advanced breeding lines known to exhibit resistance to Russian wheat aphid for use in her wheat breeding program. She and a post-doctoral scientist described several new genes for resistance to this pest. Also, in collaboration with USDA scientists at Pendleton, Zwer quantified the impact of Russian wheat aphid infestations on growth and development of wheat roots and foliage (Elsidaig and Zwer, 1993; Zwer et al., 1994).

The only other report of Russian wheat aphid damage occurred in an experiment that Dr. Richard Smiley conducted in a commercial field near Echo, OR during the 1996 crop year. Two trials were placed into a field to study methods for controlling Fusarium crown rot. One experiment included 20 winter wheat varieties for which the seed had been treated with two fungicides. The other experiment examined 12 seed treatments. Monitoring of the trial showed that emergence was delayed by high-temperature seed dormancy caused by excess soil temperature in the seed-zone at the time of planting. The moist, warm soil was very favorable for development of Fusarium crown rot. During late fall the plants were invaded by Russian wheat aphid, except for plots with seed treated with a fungicide plus an insecticide (imidacloprid; Gaucho). Stands of wheat in all plots in both experiments looked uniform and normal when winter settled in. The winter was cold and the soil froze to a depth of several inches. When the temperature warmed during the spring, with few exceptions, most plots of wheat in both trials were showing extreme signs of winter kill. The exceptions included all replicates where wheat seed had been treated with the insecticide, which exhibited very little Russian wheat aphid

Russian wheat aphid combined with winter damage, showing winter wheat during the spring after seed was either treated with an insecticide (green plots) or was not treated damage and produced good grain yields. All other plots produced very little wheat. It was concluded that the early stress factors and especially the invasion by Russian wheat aphid predisposed the wheat to winter kill. This observation prompted many producers to begin applying higher rates of the insecticide as a standard component of their protective treatment for wheat seed.

Hessian fly

This insect pest was first detected in eastern Oregon during 1980, when Dr. Ronald Rickman observed that it was present on spring wheat at the Pendleton Station. Rickman reported that occurrence to Darrell Maxwell, an Umatilla County Extension Agent, and to two entomologists; Drs. Glenn Fisher, at Corvallis, and Keith Pike, at Prosser, WA. Those four individuals conducted a survey of 64 fields in three local counties during 1981. They found that the Hessian fly was present in about half the spring wheat and irrigated winter wheat fields in Umatilla County. One field had 84 percent of the wheat stems infested by the Hessian fly. It was also observed in less-damaging proportions in irrigated winter wheat fields at low elevations in northern Morrow County. No wheat fields were found to be infested by Hessian fly in Union County. Fisher et al. (1981) published an extension bulletin to alert growers of the presence of the pest, symptoms of plants that are infested, the biology of the insect, and management practices proven to be useful in other regions.

After 1981, damage from Hessian fly has been reported at regular intervals on spring wheat in eastern Oregon and Washington. Several experiments at the Sherman and Pendleton stations were severely damaged by this insect. For instance, during 2001 and 2002, spring wheat varieties and advanced breeding lines were being compared for tolerance to Fusarium crown rot at both dryland experiment stations. The varieties were from Dr. Kim Kidwell's spring wheat breeding program at Washington State University, where breeding for resistance to Hessian fly was an important objective for the breeding program. At Pendleton and Moro, each of the 33 varieties in the replicated test were planted with or without supplemental inoculum of the crown rot pathogen. During both years, Hessian fly infested plants in the crown rot trials. The number of fly puparia in individual tillers of each variety was quantified in each plot by Dr. Smiley's assistants. Wheat yields and test weight were also determined. Smiley et al. (2004) reported that some wheat entries were very susceptible and others were completely resistant, which was the first information of that type for the advanced breeding lines of spring wheat. That report also was the first report that quantified the economic consequences of Hessian fly damage in the Pacific Northwest. Grain yield was highly influenced by Hessian fly, with a calculated yield loss of ¼-bushel for each percentage of tillers showing symptoms of fly damage. The fly also reduced the market grade of wheat from U.S. No. 1 to U.S. No. 3 during one of those years. Damage became especially acute when more than 50 percent of plants contained at least one puparium during 2001 and more than 15 percent of plants during 2002. During one year, 11 varieties having more than 50 percent infested plants yielded 70 percent less grain than 11 varieties that had less than 50 percent of the plants infested. The value of spring wheat harvested from Hessian fly-resistant varieties was \$47 to \$70 per acre more than from susceptible varieties, without including price discounts for reduced market quality in fly-affected wheat.

Hessian fly damage; lodging of unharvested Alpowa spring wheat at Pendleton (2002)

The Hessian fly also affected spring wheat in two nematode-control experiments during 2001. Identical trials were planted at the Pendleton Station and south of Mission, OR. Five wheat varieties were planted into soils that were already infested with root-lesion nematodes. Each variety was planted into pairs of drill rows that were either treated with an experimental nematicide or were planted without that treatment, as described previously in the wireworm section. The nematicide prevented Hessian fly from laying eggs in the wheat. Smiley et al. (2004) reported Hessian fly and root-lesion nematode each reduced wheat yield, and that the best explanation of yield loss for those experiments was from a combined consideration of damage from both pests.

Other Insect Pests

The second insect specifically noted in annual reports from the dryland stations was the grasshopper. The 1915 Sherman Station Annual Report stated that considerable damage was caused by grasshoppers. These insects ate most of the leaves and tips of the ears off all the corn varieties, and shattered nearly all of the late-maturing oat varieties. The report went on with "*Poisoned bran mash was used to kill them, and checked their ravages to some extent*." During that same year it was stated that the wheat straw worm also attacked some varieties of spring club wheat, but did little damage.

In 1917, all 54 corn varieties under trial at the Sherman Station began to be eaten by cut worm shortly after the seedlings emerged. A poison bran mash was spread in an attempt to control the pest. But the invasion of cutworms really didn't have any impact on that experiment; severely dry weather prevented any of the corn varieties from maturing. During the 1970s the cutworm and the grass seed gelechiid were reported to be the most destructive insects in grass seed production fields in Union County. Those infestations were studied by Dr. J. A. Kamm, a USDA entomologist from Corvallis, and more recently by Dr. Darrin Walenta, an Union County Extension Agent.

More recently, Dr. Walenta has also studied the highly damaging cereal leaf beetle which was first identified in Oregon in 1999. That beetle caused damage to Dr. Smiley's cereal cyst nematode experiments in Union County, in spite of insecticide applications that were made to reduce the damage. The cereal leaf beetle is now present in at least eight Oregon counties.

Other insect pests identified at the Pendleton Station and other areas of eastern Oregon included the wheat head army worm and wheat sawflies. Those pests were studied by Mary Corp, Umatilla County Extension Agent, and Dr. Silvia Rondon, Oregon State University entomologist at the Hermiston Station. In crops other than small grains, there have been a variety of insect pests that have had the potential to damage multiple crop species that were being evaluated by numerous agronomists and soil scientists.

***References*:**

Annual Reports from the Sherman and Pendleton Stations (Appendices 5 and 6)

Letters sent to or from the Station Superintendents

Elsidaig, A. A., and P. K. Zwer. 1993. Genes for host resistance to Russian wheat aphid in PI294994 wheat. Crop Science 33:998-1001.

Fisher, G., K. Pike, R. W. Rickman, and D. Maxwell. 1981. The Hessian fly in Oregon. Oregon Agricultural Experiment Station Circular of Information 1093.

Lane, M. C. 1931. The Great Basin Wireworm in the Pacific Northwest. USDA Farmers' Bulletin No. 1657. US Government Printing Office, Washington, D.C. 8 pages.

Smiley, R. W., J. A. Gourlie, R. G. Whittaker, S. A. Easley, and K. K. Kidwell. 2004. Economic impact of Hessian fly (Diptera: Cecidomyiidae) on spring wheat in Oregon and additive yield losses with Fusarium crown rot and lesion nematode. Journal of Economic Entomology 97:397-408.

Zwer, P. K., M. G. Mosaad, A. A. Elsidaig, and R. W. Rickman. 1994. Effect of Russian wheat aphid on wheat root and shoot development in resistant and susceptible genotypes. Crop Science 34:650-655.

Chapter 23 - Livestock

During the first four decades of the Sherman and Pendleton Stations, the Superintendents communicated at great length to resolve animal-related issues of all descriptions. Some of those topics included the purchase, health, death or sale of draft horses, hog-feeding trials conducted on the Sherman Station, geographic surveys on the prevalence of squirrels, methods for controlling gophers, species of pasture grasses and legumes to plant to prevent bloat in sheep, setting up animal feeding studies, providing materials to others for use in studies of animal rations, mortality of animals that were grazing certain types of pastures, and even a challenge regarding the quality of horses being used on the Sherman Station. Several examples of these issues are encapsulated in this chapter.

Power Source

Draft horses were the primary source of power for field implements when the Sherman Station was established, and they were still in common use when the Pendleton Station was being established in 1928. Original documents show that the Sherman Station began purchasing teams of draft horses in 1910. A letter from Harry Umbarger to Henry Scudder, dated Oct. 18, 1909 stated "*Dear Scudder: Regarding teams, will say that I have so far been unable to find anything as satisfactory as Powell's team. I tried to bring him down to $500 but he refuses to take a cent less than $550. The $400 team, about which I wrote you, is a light one, in good condition weighing about 1400 lbs. This team would probably fill in very nicely for our next draft team. In connection with the team, I might suggest that we shall need a wagon and harness next week, especially the wagon. As you say, the harness would probably better be bought here*." However, Umbarger kept searching because he and Mr. Powell were not able to agree on a price. In a letter dated March 10, 1910, from Umbarger to William Jardine, Agronomist-in-Charge, Dry Land Grain Investigations, USDA-BPI, Washington, D.C., it was stated "*We have our teams. Some of the machinery has not yet arrived, but we are hoping to begin work next Monday. At present I see nothing to hinder our carrying on the work as planned.*" Thus, by the spring of 1910, the station owned two teams, a pair of 1,600-pound 'heavy' horses for 'heavy' work and a pair of 1,400-pound 'light' horses for less demanding jobs. The Sherman Station also rented addition teams during peak seasons from 1909 until 1912. For instance, an invoice dated May 31, 1912 was for payment to O. B. Messinger, Moro, Oregon "*For hire of two horses four days at 50¢ a day for each horse. Horses worked on May 24, 25, 27, and 28. $4.00 total claimed*."

The first tractor was purchased at the Sherman Station in 1928. It was a Caterpillar 15 track-type 'crawler.' However, the Sherman Station continued to use both teams and the tractor on jobs for which each source of power was most economical. Since different styles of hitches were required to pull an implement by a team or a tractor, the hitches were slowly converted from horse to tractor power. The last horse team at the Sherman Station was used in 1948.

The Pendleton Station began purchasing implements and teams during late 1928. The station land had been fallowed during 1928 and all except a small experimental area was planted uniformly to winter wheat during October. Horses were rented and a teamster was paid for the general farming in 1928. In a letter dated October 27, 1928, from David Stephens to Mr. R. F. Whelan, Office of Dry Land Agriculture, USDA, Washington, D.C., it was stated "*I am inclosing a voucher for $174.75 for one drill and harrow purchased from the John Deere Plow Company, Portland, Oregon. … As you probably know the title for the land for the Co-operative Field Station at Pendleton was not acquired until late in September, and it was necessary to prepare the land and seed it at the earliest possible date. … We will have to purchase for the Pendleton Station four good horses. These may cost us as much as $200.00 each*."

The purchase process continued into the spring of 1929. At least 10 teams were evaluated and dismissed before two teams were purchased. For instance, a letter dated March 14, 1929, from George Mitchell to Mr. F. E. Meloy, USDA-BPI, in Washington, D.C., stated "*Mr. Barr's team was rejected for the following reasons: 1) Underweight, Mr. Barr stated that they weighed not less than 3400 pounds, the team actually weighed 3200 pounds. 2) Not matched, one was a smooth chunky horse while the other was a tall rough type. 3) One horse did not have a good action walking 'flat footed'*." Two teams, heavy and light, as at the Sherman Station, were purchased by summer of 1929. Also, as at the Sherman Station, a Caterpillar 15 tractor was also purchased in 1929 for use at the Pendleton Station. The teams and tractor were used on jobs for which each type of power was the most efficient. Perusal of the purchase invoices from that period was truly interesting. Mixed among the same stack of original invoices were invoices and payments for harness oiling, harness repair, horse dentistry, horse shoeing, hay for the horses, tractor oil and fuel, tractor clutch repair, new fan belt for the pickup, radiator repair and new brake lights for the pickup, and an endless mixture of needs for these transitional technologies.

The mixture of technologies continued until 1946. During the transition there were many communications that regarded the horse teams at the Pendleton Station. For instance, George Mitchel sent the following notification to USDA offices in Washington, D.C. in a letter dated December 2, 1939. He stated "*One of our big horses died this week. Death resulted from a number of complications of old age, pneumonia and abcesses. The horse … was about 19 years old … It will be almost impossible to find a mate for the remaining horse. I think it would be best if we bought a new team, keeping the old horse for odd jobs, much of our work such as plowing and binding we can use three horses.*" The USDA clearly decided that Mitchell had provided insufficient information. The USDA replied by directing Mitchell to provide a full description of the dead horse and the purchase date (it was in 1929) so they could remove the horse from the Federal inventory. Two months later, in February 1940, Mitchell bought a heavy team of Belgian horses even though the station had been operating the tractor for the past 11 years.

Mitchell continued to sell and buy teams until 1946, but may have reduced the number of horses to a single team at the Pendleton Station in 1942. In a letter dated January 11, 1943, from Mitchell to Ray Jeremiah, at Waitsburg, WA, it was stated "*I wish that you would return the harness, halters and bridles you borrowed when you purchased the team from this station. As these are federal government property … I must have these items on the station at the time of inventory. … otherwise they will be reported to the proper federal authorities for action*." In a related matter, Hamley and Co., of Pendleton, sent an invoice dated September 17, 1943 for the purchase of new harnesses and oiling and repairing of older harnesses for the work teams. Other invoices at the time were to pay for 'Horse dentistry.'

Mitchell sold another team in 1943 because they were considered unsafe for use by the teamster. In a letter dated July 30, 1943, to Ralph Besse, Vice Director of the OAES, at Corvallis, Mitchell stated "*I would like to have authorization to dispose of the team of horses owned by this station. … This team is a wonderful team as far as amount of work they can do in a day, but are very nervous and will try to run away at any opportunity, they finally got away on July 5 with a hay wagon and ended up straddling the mower in front of the implement shed. Fortunately, little equipment was broken up and no one was hurt, we may not be so fortunate next time. After this experience I would be willing to sell them rather cheaply.*" The sale was authorized and Mitchell immediately began searching for another team to purchase. In a letter to Mitchell from the Oregon State Board of Control, in Salem, dated February 19, 1944, it was stated "*We are in receipt of your requisition #17 C5R57 covering one only span of draft type horses to be purchased from Mr. J. E. Harvey, Pendleton, Oregon. The Eastern Oregon State Hospital, Pendleton, have two teams which they wish to dispose of. …*[Before your purchase can be authorized we] *ask that you kindly contact …. and ascertain whether or not … the teams they have will be suitable for your work.*" Mitchell responded that neither team would be suitable. One team was too nervous to be used at the station by 14- and 15-year-old boys during the summer, and the other team was poorly matched. He stated "*I have looked over a great many teams in the past three weeks, the team that Mr. J. E. Harvey offers for sale meets our requirements perfectly*." Mitchell bought the team from Harvey but then one died in 1945. In 1946 Mitchell presented the following inquiry to the Agricultural Experiment Station at Corvallis: "*I would like to have authorization to sell our one work horse. We are doing all our work with tractors now and have no further need of a work horse on the station. There is no market for work horses in this area, I think that I can probably get about $40 for this work horse, just about the price they bring as fox feed*."

Feeding Studies

Soon after the Sherman Station was established it became an even more expansive operation than had been initially envisioned. Scientists at Corvallis began requesting that the Station begin to establish animal studies. For instance, on July 21, 1911, James Dryden, Department of Poultry Husbandry, sent a letter to Superintendent Umberger. The letter included these passages: "*Dear Mr. Umberger: I have been discussing with Director Withycombe and Prof. Scudder, the advisability of starting a poultry experiment at Moro this fall. The plan is to make it a pasturing experiment on wheat stubble fields. I want to secure about 500 chickens, preferably cockerels two or three pounds in weight, put them in colony houses on the wheat stubble and keep them there till in good condition for market, probably six weeks or two months. I presume there should be as much as 50 acres or 100, depending on the amount of grain that was shattered. The idea* *is to move the houses onto fresh ground every few days or a week, and we would have a man with them to take care of them and keep the necessary records*." Umberger responded a week later by stating "*An experiment such as you mention would be especially appropriate at this station this year, as much of the grain is too short to cut, and consequently will be lost unless pastured*." The study was conducted and the last of the cockerel-related letters between Dave Stephens and the Poultry Department were written in 1920.

Almost immediately after the initial request for poultry studies, Umberger received another letter from Director Withycombe. That letter, dated September 8, 1911, made a similar request for hog-feeding studies. Those studies were also initiated and continued into the 1940s. For instance, from 1943 to 1946, the station conducted hog-feeding experiments. Three pastures were fenced and each pen was to hold 10 to 15 pigs; the actual number varied from year to year. Each lot of pigs consisted of a mixture of three breeds and each lot was fed a different ration. Weights were measured and rate of gain was calculated. Other measurements included the meat yield at the butcher shop, and the cost of feed per pound of pork. The breeds in the tests included Duroc, Berkshire, Poland China, Hampshire, and Chester White-Duroc crosses. Economic analyses were conducted to determine the most efficient feeding regime for producing a pound of pork.

Hog-feeding experiments at the Sherman Station (1944)

Hay was still an important commodity in the region into the late-1940s because the stations and some farmers were still using teams of horses for at least some farming operations. Dave Stephens alluded to the situation in which some farmers who had purchased tractors found that they could not be operated economically when wheat prices were low during the 1930s. In a letter to Henry Scudder, dated July 24, 1931, Dave Stephens stated that "… *The failure of much of this land to produce any crop this year and the very low yield obtained on some of it, will doubtless mean that some of this land will not be sown to a crop next year. … It may take another year of low prices to eliminate much of this land, but the elimination of most of our low-producing lands is a foregone conclusion if present low wheat prices continue. … rather gradual, as operators will try to hang on as long as the banks will carry them. The scarcity of jobs in other industries also will tend to keep the farmer on the land as long as he can possibly stay there*." "*The large operators, like the small ones, have been losing money during the past two years because of the low yields and low prices. And the bigger the acreage the bigger the loss*." "… *One interesting thing this year is an increase in the use of horses, a number of folks with tractors are using horses to save the cash expense incident to the use of the tractor. These tough times may cause a swing back to horses again, because the horses can be raised and kept on the farm with very little cash outlay*." The continued use of horses during the mid-1940s was also illustrated by photos in the 1943 Station Report, which showed a team pulling a hay wagon and another team pulling a sickle bar to cut hay. At that time, hay at the Sherman Station was cut from 11 varieties of winter wheat, spring wheat, spring barley and oats and sent to the Eastern Oregon Livestock Experiment Station at Union be tested for the value of each type of hay in livestock rations. During 1942, the station also collected wheat chaff and sent it to the station at Union, where it was also evaluated as a feedstock in various livestock rations.

Poisoning

During the summer and fall of 1928 many dozens of letters were exchanged between Dave Stephens and State and Federal animal pathologists, chemists, botanists and bacteriologists. In Sherman County and in several adjacent counties more than 150 cattle and horses died of mysterious causes. An absence of fever prior to death of the animals seemed to rule out a long-list of infectious diseases that were each considered carefully by three State and Federal veterinarians. The veterinarians claimed that the symptoms were very similar but not identical to strychnine poisoning. Some farmers also suspected the cause to be strychnine, which had been set out during a predator control program intended to poison coyotes. The program was run by the Bureau of Biological Survey. But no poison had been set out on or even close to some of the affected farms. The biological survey staff therefore concluded that it was impossible for strychnine to be the cause of the problem. Farmers slowly came to the same conclusion. Scientists examined affected fields to determine if the toxin-producing ergot disease may be occurring in seed heads of pasture grasses. No ergot was detected. The deaths were therefore thought to be possibly related to the feed, pasture or stagnant water.

Stephens coordinated further efforts to determine a cause for the problem. He spent many weeks traveling to inspect animals, pastures, feed supplies and water. He took detailed notes on the animal's symptoms before and after death. He collected and shipped dozens of grain sacks filled with plant samples for analytical tests conducted by chemists, for identifications of plants by botanists, and for establishment of cattle and guinea pig feeding trials by animal pathologists. He also sent water samples for use by bacteriologists and the feeding trials with guinea pigs. Some of the guinea pigs died after eating one of the plants. The animal science department shipped two Jersey calves from the Willamette Valley to see how they fared while grazing on an affected farm pasture in Sherman County. The affected farm had lost 28 head of cattle five weeks earlier. In a little more than two weeks, one of the imported calves developed typical symptoms and died three days after showing the first symptoms. A postmortem found nothing of value. The other calf died soon thereafter. Upon searches of the pasture, Stephens found some plants of lupine, yarrow, cheatgrass, rye, and the native bunchgrass, Sandberg bluegrass.

Dave Stephens, upon request, in October 1928, sent four grain sacks of lupine seed to Salina, UT for use in field studies at the Salina Experiment Station. Those studies were coordinated by C.D. Marsh, Physiologist-in-Charge of Investigations of Stock Poisoning by Plants, Bureau of Animal Industry, USDA, Washington, D.C. Plant sampling, feeding studies, and toxicology research continued into the 1930s. On December 9, 1930, Stephens received results from the feeding studies in Utah. They offered to send moving pictures to Moro but Stephens told them to send it to veterinarians in Corvallis because there was no moving picture machine in Sherman County or nearby, and it would be difficult to transport such a machine from the extension office in Corvallis.

On April 4, 1931, the scientists at USDA sent Stephens a final report that poisoning of cattle by *Lupinus laxiflorus* variety *silvicola*, as shown in the moving pictures, caused symptoms very similar in many ways to those exhibited by the sick cattle they saw in Sherman County. But, again, there were certain differences. It was suggested that reasons for those differences should be determined. They needed to determine relative differences in toxicity of various growth stages of the lupine, and of differences between leaves and stems. The research was therefore continued. On April 11, 1931, Dave Stephens sent another 50 pounds of plants to Salina so the plant material could be tested before the plants entered the seed pod growth stage. By June 12, Stephens shipped another 150 pounds of lupine in the post-bloom stage. Dave Stephens was obviously a central resource for this research on lupine poisoning of livestock in north-central Oregon.

Politics

The use of livestock also involved some decidedly political maneuvering. One particularly interesting exchange regarded the quality of draft horses at the Station, as it related to the image being presented by the College. When establishing the Station, Umberger paid a great deal of attention to acquiring two teams of high-quality horses that were matched in color. The larger team was to be used for heavier duties such as plowing, and the lighter team was to be used for pulling wagons, cutting hay, harrowing and other light duties. An example of his diligence was noted in his letter to Henry Scudder, dated November 9, 1909. The letter stated "*I am going out in a day or two to look at a 1600 pound team, straight color and guaranteed without a single blemish anywhere, for $450*." Three years later, in 1912, Stephens submitted an invoice for the College to pay Mr. [name was stated but is omitted here] for "*Stallion service for two mares 'Buss' and 'Fanny' at $20.00 each; Total of $40.00*."

On October 8, 1915, in a 1-page letter to Dave Stephens from E. L. Potter, Professor of Animal Husbandry, at Corvallis the following statement was included. "*At a recent meeting of the Oregon Horse Breeders' Association … a rather strong criticism was made of the Agricultural College because it was stated that at the Experiment Station at Moro the mares were being bred to a horse that was licensed as a mongrel that was unsound. … tell me the real situation. As you are of course aware, the use of sound, pure bred sires has been the war cry of the extension work of this department, and a charge of this sort of course completely counteracts all our efforts toward improvement*." Stephens replied on October 11, 1915, stating "*For the past three years the mares on the station have been bred to pure-bred stallions. Before I came here, the station mares were bred to Mr.* [name was listed but is not printed here]*'s black Percheron horse. Many horsemen and the owners of this horse claimed he was a registered pure-bred horse, but I believe he was listed in the State Stallion Registration book as a mongrel. I think if Mr. Umberger, my predecessor, had known that this horse was not a pure-bred animal, he would not have bred the station mares to him.… I wonder if the criticism of the station was not made by someone in Moro who is rather sore because our mares have not been bred to a horse which the gentleman owns himself*." Potter then replied "… *I would* *like very much to know the names and owners of the stallions which have been patronized by the Station in the last three years*." Many more letters were exchanged. Near the end of that series of communications, it was stated in a letter dated December 6, 1915, from Potter to Stephens, that "*As I presume you suspicion, the man who made the complaint was Mr.* [name was listed but will not be repeated here]. *At our ... meeting, Mr*. […] *made the statement that he did not think the state was doing exactly the proper thing in breeding to stallions that were licensed as mongrels and as unsound. I said nothing ... As I stated in my previous letter, the* […] *horse was licensed as unsound and as a mongrel. The* […] *horse is licensed as a pure bred horse, but as unsound, having sidebones. It therefore appears that Mr.* […] *knew pretty much what he was talking about* [at the breeders meeting]."

Community Service

It has been common for station staff to assist county agents in preparing crop and animal judging competitions at county fairs. That activity generally required only a minor commitment of time and materials. However, several exceptions were noted in archived documents. John Foster Martin, the first long-serving cereal breeder at Moro and Pendleton, organized Intercollegiate Crops Judging Contests at the Annual Pacific International Livestock Exposition in Portland. Land grant colleges across the nation sent judging teams to evaluate the many dozens of sheaves of wheat, oats, barley and legumes prepared by Martin. That activity required as much as three weeks of Martin's time, including a non-reimbursed week in Portland. Another example specific to this livestock chapter is also described.

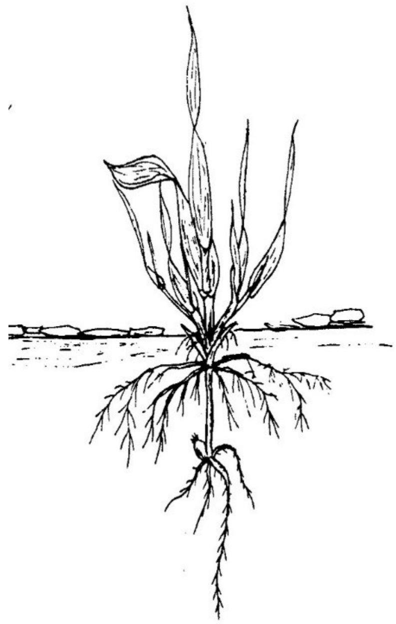
Merrill Oveson was a member of the Pendleton Rotary Club. Oveson was the chair of the Club's Livestock Auction Sale Committee, also known as the Fat Stock Sale. Oveson coordinated this major event for several years during the early 1960s. The sale included beef, hogs and sheep. Members of 4H and FFA clubs competed in showmanship and livestock judging contests. The formal program culminated with a public auction to sell the animals. Oveson coordinated committees on rules and regulations, publicity, finances, communications with prospective buyers, coordination of professional animal judges and graders and student showmen, Rotarians appointed to visit the home of each potential exhibitors prior to the show, places and times to weigh animals, grounds (holding pens, lights, loud speaker, seats, and getting stock in and out of the ring), ribbons (present ribbons to winners and assist in the auction ring), and animal disposal (assist in transferring livestock to slaughter houses designated by the buyers). Oveson also administered rules and overnight vigilance regarding the last permissible animal feeding and watering during the evening before the stock were to be weighed on the day of the contest. After animals were weighed, they were officially judged and graded by professionals. The 4-H and FFA members then competed in showmanship contests and livestock judging contests. After the contests and awards ceremony, an auction was held during the evening. After being sold, the animals were tied securely in their stalls and guarded overnight. The next morning, the animals were moved to slaughter houses designated by the buyers. Oveson devoted a great amount of time and dedication to his chairmanship duties for the annual Fat Stock Sale.

***References*:**

Annual Reports from the Sherman and Pendleton Stations (Appendices 5 and 6)

Letters sent to or from the Station Superintendents

Smiley, R. W. 2020. Rotary Club of Pendleton: The First Century (1920 – 2020). Sykes Brothers Printing, Pendleton, OR. 215 pages.



Chapter 24 - Extension Education

Scientists and staff at the Sherman and Pendleton stations have maintained active educational programs since the stations were established. The programs have included many different formats, including written bulletins, tours of field experiments, participating in tours or meetings coordinated by county extension agents and by commercial agri-businesses, traveling to farmer's fields to evaluate the health of the crop, providing issue-specific training for crop insurance adjusters and agricultural bank lenders, preparing displays for county fairs, presenting radio programs, providing written or verbal responses to individuals, sending alerts via social media platforms, and other types of communications with the public.

Selected examples of these activities are cited in this section to illustrate the broad nature of the extension component of a researcher's activities. Examples of extension bulletins written entirely or in part based on research conducted at the Sherman and Pendleton Stations include the following titles included in the publications shown in Appendix 3.

1. Bechtel and Corp. 2001. Flexible crop-share leasing agreements
2. Chozinski, Horneck and Wysocki. 2013. Eastern Oregon liming guide
3. Corp, Horneck, Wysocki and Lutcher. 2012. Monitoring soil nutrients in dryland systems using management units
4. Corp, Machado, Ball, Smiley, Petrie, Siemens and Guy. 2004. Chickpea production guide
5. Douglas, Wysocki, Zuzel, Rickman and Klepper. 1990. Agronomic zones for the dryland Pacific Northwest
6. Fisher, Pike, Rickman and Maxwell. 1981. The Hessian fly in Oregon
7. Hagerty and Smiley. 2017. Field guide for diagnosing common wheat maladies of the Pacific Northwest.
8. Hagerty, Kroese, Mundt, Heesacker and Zemetra. 2019. Eyespot of wheat: How to identify and control this common fungal disease
9. Hunter, Gerard, Waddoups, Hall, Cushman and Alban. 1957. Wheat fertilizer experiments in the Columbia Basin
10. Jackman, Stephens and Richards. 1936. Crested wheat grass in eastern Oregon
11. Karow and Pumphrey. 1986. Growing rapeseed in Oregon's drylands
12. Karow and Pumphrey. 1986. Potentials and problems of rapeseed production in Oregon
13. Karow and Zwer. 1993. New winter wheat varieties, Rohde - a winter club wheat
14. Karow, Klepper, Rickman and Toll. 1993. Early growth and development of cereals.
15. Karow, Zwer, Barnum, Bohle, Kolding and Kronstad. 1993. Winter wheat varieties for 1993
16. Lane. 1931. The Great Basin wireworm in the Pacific Northwest
17. Lutcher, Horneck, Wysocki, Hart, Petrie and Christensen. 2007. Winter wheat in summer-fallow systems-intermediate precipitation zone
18. Lutcher, Horneck, Wysocki, Hart, Petrie and Christensen. 2007. Winter wheat in summer-fallow systems - low precipitation zone
19. McDermid. 1970. Irrigation studies in Sherman County
20. Naire. 1956. Evaluation of dry land crop rotation experiments at Sherman Station
21. Oveson and Hall. 1957. Longtime tillage experiments on eastern Oregon wheat land
22. Petrie, Wysocki, Horneck, Lutcher, Hart and Corp. 2007. Winter wheat in continuous cropping systems - high precipitation zone.
23. Pumphrey, Klepper, Rickman and Hane. 1980. Sandy soil and soil compaction
24. Pumphrey. 1961. Winter wheat fertilization in Northeast Oregon
25. Rohde, Hall, Johnson and Hoffman. 1956. Performance of wheat varieties in eastern Oregon
26. Ross. 1972. Eastern Oregon windbreak trees and shrubs
27. Schwendiman. 1976. Grasses and legumes for conservation use in semiarid wheat-fallow areas of eastern Oregon
28. Smiley, Cook and Paulitz. 2002. Controlling root and crown diseases of small grain cereals
29. Smiley, Cook and Paulitz. 2002. Seed treatments for small grain cereals
30. Smiley. 1992. Estimate of cultivated acres for agronomic zones in the Pacific Northwest
31. Smiley. 2015. Plant-parasitic nematode affecting small grain cereals in the Pacific Northwest.
32. Smiley. 2015 Root-lesion nematodes: Biology and management in Pacific Northwest wheat cropping systems.
33. Smiley. 2016. Cereal cyst nematodes: Biology and management in Pacific Northwest wheat, barley and oat crops.

34. Stephens and Woolman. 1922. The wheat bunt problem in Oregon
35. Stephens, Oveson and Mitchell. 1943. Water requirement of wheat at the Sherman Station
36. Stephens. 1924. Dry-farm crop rotation experiments at Moro
37. Stephens. 1944. Conservation practices on wheat lands of the Pacific Northwest
38. Washburn and Scudder. 1926. Cost of using horses, tractors and combines on wheat farms in Sherman County
39. Wysocki and Corp. 2013. Dryland cropping systems: Edible mustard
40. Wysocki, Corp, Horneck and Lutcher. 2013. Irrigated and dryland canola nutrient management guide
41. Wysocki, Lutcher, Horneck, Hart and Petrie. 2005. Winter wheat and spring grains in continuous cropping systems - low precipitation zone
42. Wysocki, Lutcher, Horneck, Hart and Petrie. 2012. Winter wheat and spring grains in continuous cropping systems (low precipitation zone) fertilizer guide
43. Wysocki, Lutcher, Horneck, Hart, Petrie and Corp. 2005. Winter wheat in continuous cropping systems - intermediate precipitation zone
44. Wysocki, Lutcher, Horneck, Hart, Petrie and Corp. 2007. Winter wheat in continuous cropping systems - intermediate precipitation zone

Field tours have always been a key event for communicating results of research at both stations. That activity began in 1912, the year after the first real experiments were established at the Sherman Station. Field tours began soon thereafter in other counties, including Umatilla County. For instance, agronomists from the Sherman Station participated in tours of off-station variety testing nurseries in Umatilla County at least five to 10 years before the Pendleton Station was established. Likewise, farmers, extension agents and businessmen from Umatilla County made annual trips to examine the experiments being conducted at the Sherman Station.

That first event at the Sherman Station was grander than the average field tour. Dave Stephens distributed invitations by convincing newspaper editors to print announcements. The letters to the newspapers were as follows: "*My dear Sir: In order to get as many farmers as possible to visit the experiment station at Moro, we have set aside Saturday, June 29, as FARMERS' DAY. We should like to have every farmer in eastern Oregon visit the Station on that date and inspect its work. The O.W.R. & N. Railroad Co. will give a rate of one and one-third fare for the round trip to Moro from all points on the Shaniko, Condon, and Heppner branches, the rate being effective June 28th to 30th inclusive. An appropriate program will be rendered and the work of the Station in all its phases will be explained. The principal speakers will be President Kerr, Dr. Withycombe and Prof. Scudder of the Oregon Agricultural College. We shall very much appreciate it if you will notify the people of your community of the excursion through the columns of your paper. I trust that you will be able to spend the day with us yourself. Very truly yours, David E. Stephens, Superintendent*."

<u>Sherman County Agricultural Agents</u>

Claude Calkins	1918-1921
Walter Carpenter	1921-1923
Perry Johnson	1933-1936
LeRoy C. Wright	1936-1949
Thomas W. Thompson	1949-1967
Martin Zimmerman	1962-1971
Gordon Cook	1971-1978
Alexander (Sandy) Macnab	1979-1984
Brian Tuck	1983-1994
Alexander (Sandy) Macnab	1993-2016
Brian Tuck	2017-2019
Jacob Powell	2019-

The Station Superintendent was the primary source of information for the farmers during Stephens' first three years at the Sherman Station. There were no county agents until about 1918. Stephens visited farms and went to meetings very frequently but found it difficult to do so. All of his travel through 1914 was via the railroad or by getting someone with a car to take him wherever he needed to go. In July, 1914, Stephens implored upon the College to help him with that inconvenience. In a letter to Henry Scudder, he stated "… *I do need some means of conveying me from place to place, and I could be of much more service to the farmers here, if I had a small Ford car or its equivalent. Would buy one if I could in some manner get the State or government pay me $15 or $20 a month to help pay for it.*" A week later Scudder responded with the following: "*Cheer up, old man, you will get a machine yet. You certainly ought to have one if you are going to get around the country as much as you should. Will certainly manage it in some way or another by next season*."

While extension work can be highly satisfying, it also can be depressing at times. On October 24, 1914, David Stephens received a letter from the College President. The letter lent a body blow to the 3-year-old Sherman Station. It stated "*My dear Mr. Stephens: In an editorial which appeared in the Medford*

Mail Tribune on October 14th occurs this paragraph. 'The station at Moro, costing the State $2,500 a year for the purpose of demonstration as to the kind of cereals especially adapted to that community, is such a failure that the farmers refuse to even visit it in that county.' Kindly send me at once a definite statement of some 200 to 400 words that can be used in reply either in the Medford Mail Tribune or in the other Medford paper. Very truly yours, W.J. Kerr" Stephens took great pains to script a meaningful and positive message in response to the criticism posted in the Medford Mail Tribune.

Car convoys at Sherman Station Field Tours: 1920 (left) and 1921 (right)

The Station Superintendents have always allocated a considerable amount of time to travel to events planned by County Agents, such as county fairs, field tours, and educational meetings. They also spent considerable time with the Agents and farmers from other counties that wished to be given individualized updates on the experiments at the Station. The following is just one example of a request from Fred Bennion, Umatilla County Agricultural Agent, at Pendleton. On June 8, 1920, Bennion wrote: "*When the work at the Moro Station appears to the best advantage I should like very much to work up a Farm Bureau excursion from this county. I have discussed the matter with Mr. Scharpf, Cashier of the American National Bank, and he is heartily in favor of the movement. In fact, I believe that bank will take quite a number of their customers as guest of the bank.* [We will] *drive to the Station spending two nights at Wasco and the intervening day at the Station. I should like to have Professor Hyslop and such other talent as you might see fit for the occasion. Kindly let us know regarding suitable time for the trip and suggestive plans*." Stephens responded with the following: "*We will certainly be glad to have you come and will do all we can to make your visit pleasant and profitable. The Sherman County farmers will visit us on the 24th. Any date the following week would be all right. It would be necessary for your farmers to stay at Wasco, as we have no hotel accommodations here*."

These individualized tours were continued. On May 24, 1921, Stephens notified Director James Jardine that: "*Sorry you were not with us when the County Agents were here. The agents seemed very well satisfied with what they saw and heard here. They came a day sooner than we expected them, but they stayed here two days*." … "*Hyslop wants me to give two talks during Farmer's Week …*"

Likewise, on July 1, 1922, Stephens sent another letter to Jardine, stating: "*We had a delegation of forty-five farmers from Wasco County on June 24th. They spent Friday afternoon visiting farms in Sherman County and all day Saturday on the Station.*" "*On the afternoon of Wednesday, June 27th, we had about 100 Sherman County farmers visit the Station.*"

These local tours became very popular. The 1941 Sherman Station Annual Report includes photographs of about 12 farmers from Bickleton, Washington spending a day at the station on April 28, and about 26 farmers from Douglas County, Washington visiting for a day on June 6. The report for 1940 also showed a group of about 15 students from the Farm Crops Department at Corvallis spending a day at the Station during that year. During the regular field tour sponsored by the Station during 1941, yield data were available for a 32-year period for some varieties of wheat. The rankings of yield and other performance characteristics were influencing growers to change over to higher-yielding varieties because the scientists at that time believed the common bunt problem had been conquered (see Chapter 20). The scientists also distributed up to 20 sacks of varieties of interest to various farmers and encouraged them to plant the free seed, monitor it, and report their yields and impressions. The planting of hybrid crosses increased in intensity as the breeders picked up momentum throughout the region.

Sometimes the requests required even greater time commitments. For instance, on July 22, 1922, Stephens received a detailed 3-page letter from C. C. Calkins, county agent in Morrow County. Calkins had just become the county agent at Heppner the previous year, when he moved from a similar position in Sherman County. Calkins stated that they desire to "*try out some of the different varieties of wheat which have been in question in certain communities of the County, beginning this fall. We will want to plant these on approximately an acre basis just as in Sherman County*." Calkins goes on to state that they did not have money to pay for the wheat, and he therefore requested that the Sherman Station furnish it f.o.b. Heppner. He then suggested sending enough of each variety to place the 1-acre plots at two locations in Eightmile, one at Hardman, one at Gooseberry, one on the hill south of Jordan Siding, one north of Lexington, and one in Sand Hollow. Calkins continued by stating the "*if the tests are started they should be continued for two or three years at least. What suggestion would you have to make relevant to the treatment of this wheat?*"

The off-station demonstrations were organized and installed. Calkins' letter was the first of many in which collaborative testing between the Station and most of the county agents in Oregon's northcentral and northeast counties of Oregon, and also Jefferson, Wheeler and Harney counties. By the 1940s, small cereal variety nurseries were being grown in cooperation with the county agents of Wasco, Sherman, Gilliam, Morrow and Wheeler counties. Those varieties as well as grain bundles from extension service fertilizer demonstrations were transported to the Sherman Station for threshing, cleaning and weighing the grain as well as the straw.

In a 7-page report of station activities during 1924, which was submitted by Stephens to Director Jardine, it was stated that "*Branch station employees are glad to respond, when-ever possible, to calls from farmers for assistance and to the Extension Service and County Agents for help in conducting farmers' meetings and field days ... and for farmers of Eastern Oregon to visit the Branch Station. In 1924, three successful field days were held on the Station and one at each of the grain nurseries in Umatilla, Morrow, and Wasco Counties. At the nursery at Eight-mile in Morrow County, more than 200 persons were present*."

Stephens became recognized as the local and regional 'fountain of information' during his decades of service in Oregon. He assisted homeowners as well as farmers. For instance, his communications include such topics as controlling blister beetle on flowers at a home in Moro, and the most efficient control method to kill gophers that were eating flowers in a garden at Kent. From 1928 until 1930, Stephens also participated in the "Farm Crops Radio" transmitted from Station KOAC at Corvallis. Transcripts of some of those radio presentations are held in the boxes of archived records from that time period. Some of Stephens topics included "*Spring grains for Oregon*", "*Spring Grain Varieties for Eastern Oregon*", "*Tillage and Production*", and "*Seeding and Reseeding of Spring Grains in Eastern Oregon*."

Umatilla County Dryland Agricultural Agents

Mannes Schrock	1917-1918
Frederick Bennion	1919-1926
Walter Holt	1927-1945
Victor Johnson	1945-1968
Frederick Hagelstein	1968-1972
John C. Hesketh	1972-1975
Thomas W. Thompson	1976-1980
Jerry Brog	1982-1985
Thomas Darnell (M-F)	1978-2006
Michael Stoltz	1986-2001
Mary Corp	2002-2013
Dr. Donald J. Wysocki	2014-

Extension agents for agriculture, 4-H and youth, and home-making arts became commonplace after about 1918. The agricultural agents provided training activities that were often closely tied to field demonstrations established on commercial farms. For instance, the Umatilla County extension agricultural agent began establishing field demonstrations in Umatilla County in 1918, a decade before the Pendleton Station was established in 1928. The early demonstrations in Umatilla County were very similar to the research trials at the Sherman Station, illustrating the close collaboration between the scientists at Moro and the extension agent in Pendleton. For instance, during his first year of service, in 1919, Fred Bennion established a demonstration of different wheat varieties, different smut-control treatments, and tillage methods for handling summer fallow. In addition, he provided oversight and inspection services for farmers who were producing certified wheat seed. These types of activities became common in most counties where dryland agriculture was important.

Educators from Oregon State College went to communities and farms to provide useful information for improving quality of life, which often assisted in improving the profitability of farms and in making helpful contributions to the social fabric of communities. The educators travelled first by horse and then by car. When railroads began to connect farms with markets throughout the State, the College saw the opportunity to gain access to an even broader audience. They began to mount educational displays in freight cars. The travelling exhibit was displayed and was explained to audiences in many small communities. As an example, Merrill Oveson and Bill Hall prepared an exhibit for the Union Pacific Educational Car that made a stop at The Dalles on January 23, 1948. The display from the Sherman Station described: 1) the process of wheat breeding and testing, 2) lists of winter wheat and spring wheat varieties recommended by the Station, 3) a description of the best methods for preparing and handling summer fallow, 4) a description of the many tons of soil that can be lost from fields with different tillage practices, and 5) a description of soil water storage and nitrate accumulation in fields with different methods of summer fallow.

Sherman Station's Display at 1911 State Fair

Oregon State College's Traveling Exhibit at Grass Valley (1916)

There was always an especially close relationship between the Station staff and the agricultural agents in the nearby counties. Some of those agents also conducted individual demonstrations or research on the Sherman Station rather than only on lands of cooperating farmers. Lists of Sherman County and Umatilla County agricultural agents are shown in the boxes. Comparable lists could be prepared for the other six counties in northcentral and northeast Oregon, and in the nearby counties of southcentral and southeastern Washington. All have had routine programs that were mutually complementary with those of the scientists at the Sherman and Pendleton Stations.

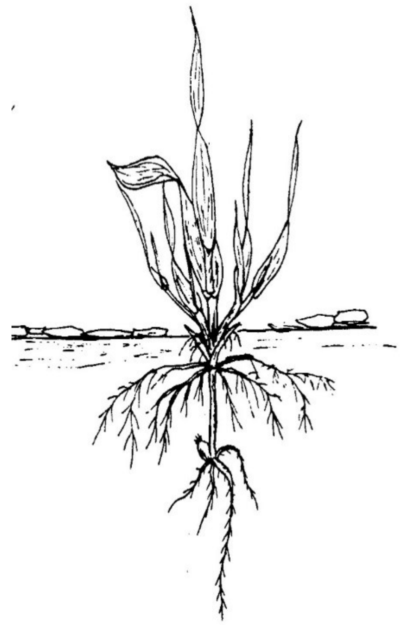
The extension agents from most counties in the dryland regions often gathered annually to make collective educational tours with well thought out agendas for becoming familiar with topics of special interest. Station scientists sometimes joined into these tours. Some of the stops on the agent tours included experiments at the Sherman and Pendleton Stations. The frequency of those group educational tours dwindled from the 1950s into the 1980s, and were curtailed during the 1990s.

None of the early staff at the Sherman and Pendleton station had formal affiliation with the Oregon State Extension Service. The extensive commitment to extension activities by the station scientists and assistants was considered a normal component of the applied research for which they were responsible.

Extension Service funding for staff at the research centers became more commonplace after about 1970. Appendix 2 lists five extensionists who have been employed at the Pendleton Station. The first three carried 100 percent appointments to the Extension Service. Most state scientists were hired with split appointments from the Extension Service and the Agricultural Experiment Station, with portions of their funding originating from each of those agencies. Those scientists are exemplified at present by Drs. Judit Barroso, Christina Hagerty and Donald Wysocki. Proportions of the extension:research joint appointments ranged from 80:20 to 20:80. Regardless of the proportion, each of the research scientists performed extensive and continuous extension programs. Likewise, scientists with 100 percent research appointments, such as all USDA scientists and Dr. Stephen Machado, also maintained active extension programs as a component of their applied research responsibility.

References:

Annual Reports from the Sherman and Pendleton Stations (Appendices 5 and 6)
Letters sent to or from the Station Superintendents



Chapter 25 - Other Contributions by Station Staff and Their Families

Employees at both dryland experiment stations have also had important influences that are far beyond than their contributions to farming practices in the region. This far-reaching influence was particularly important during the earliest decades of the Sherman Station. Influences of the Pendleton Station have also been important but in a way that differed from those of the Sherman Station. Some of the contributions from each location are described briefly to document these additional influences.

Sherman Station

The Sherman Station's influences included national and state policy issues, contributions to scientific knowledge beyond the direct agricultural applications, collaborations with other scientists and public- and private-sector agriculturists in many regions of the U.S. and internationally, and contributions to the fabric of the local community. The station staff also had important influences on the establishment or non-establishment of other branch experiment stations, and on establishment of the Oregon Wheat Growers League.

Contributions to Agricultural Policy

Dave Stephens frequently corresponded with high-level administrators, including the, U.S. Secretary of Agriculture, Federal Congressmen and Representatives, the State Governor, State Representatives, the College President, and others. He continually exerted a definitive and influential impact on policies at the national, state, and local levels. He was the first and last Station Superintendent with such a high levels of access and influence. The following are a few examples.

On December 30, 1924, Stephens sent a typewritten 5-page, single-spaced letter to W. M. Jardine, the Secretary of Agriculture. "*Dear Will: I have not had an opportunity sooner to answer your letter asking for suggestions in regard to the manner in which the President's Commission might render aid to the farmers of the northwest. ... Because of the fact that you are a "native" of the Northwest and in times past have traveled over it studying its agricultural needs and problems, we shall especially look to you to protect our interests in every way you can. These interests, I take it, will not, or at least need not run counter to the interests of the farmers of the great State of Kansas. ... if I understand aright, you are to work in conjunction with the other great men of the Commission to determine what, if anything, really ails American agriculture, generally and specifically, and to recommend remedies.*"

"*As you state in your letter, the wheat of the Northwest goes into competition with that of Australia and New Zealand in the world markets. ... I think I could easily prove to your satisfaction that we can raise good milling wheats in the Northwest, just as good as you can in Kansas at least. Most of our present commercially grown wheats, however, are not good milling wheats, but for some reason or another, they bring prices on the market here as high and sometimes higher than the high-protein, good quality wheat. I presume this is because of the export demand for these low-gluten wheats, some of which are remarkable producers in this section. No serious attempt has yet been made to improve the milling quality of present commercial northwest wheats, mainly because in our market a high-protein wheat rarely sells for a premium over a low-protein one. Farmers thus far, therefore, have been concerned only with getting high-yielding wheat varieties*."

"*The price of our wheat, therefore, is likely always to be governed by the export demand and will have to compete in Orient and European markets with southern hemisphere grown wheat*."

"*… While it is true that we can and should diversify more, especially in some of the higher-rainfall sections of the Northwest, the fact remains that the number of crops that we can profitably grow on our lands is exceedingly limited and none are so productive or desirable, everything considered, as the small grains. We may at some future date grow a somewhat greater diversity of crops, but our basic industry will likely always be wheat-raising. So whenever we are unable to raise wheat profitably we shall have hard times. And with present high costs, the farmer of the Northwest cannot get by with a price much less than a $1.25 a bushel for his wheat*."

"*… any recommendation for legislation encouraging greater crop diversification will be largely futile, so far as the Northwest is concerned. On our dry lands, most of which gets less than 11 inches of precipitation annually, very much diversification is entirely out of the question.*"

"*Another favorite topic among statesmen and would-be statesmen is that of cooperation. Many people believe that cooperative marketing is to be the solution of all our price problems. Several years ago the farmers of the Northwest plunged into a wheat marketing organization, signing up its members for six years, according to the "Sapiro Plan." The undertaking has ended in dismal failure. The idea of further legislation to encourage cooperative marketing will not meet with much enthusiastic approval among farmers of the Northwest*."

"*Your suggestion regarding the possibility of increasing the consumption of wheat and wheat products in the Orient is good. I have often thought that if only a very small percentage of the population of China and Japan could be educated into eating wheat products it might materially increase consumption and reflect on wheat prices*. [But] *I suspect that the average 'Chink' or Jap is too poor to buy any of our wheat at a price that we would like to have him pay.*"

The letter to Secretary Jardine concludes with several paragraphs of personal thoughts regarding health issues facing each of these men and members of their families, catching up on what the children are doing, as in going to college, and the following: "*Kate joins me in sending kind regards and best wishes*."

Stephens also injected his opinions into many issues of importance in State government. On February 7, 1925, he sent a 3-page letter to Mr. C.A. Tom at the House of Representatives, Salem "*I am very glad you sent me copies of House Bills numbers 60 and 258, because I think both of these bills, if passed, would seriously interfere with the work of the Branch Experiment Stations in Eastern Oregon. House Bill No. 60 is especially objectionable because it requires that all moneys derived from sales of products on these stations be turned in to the general fund, thereby reducing the present meagre income of these stations. … it would take away the present incentive of so handling our work that the largest possible income can be derived from sales … for paying our operating expenses*."

"*House Bill No. 258 also, if it becomes a law, would hamper our work to a great extent if we were unable locally to buy supplies, machinery extras, hardware, etc., that are always needed in small quantities almost daily during the summer months. … It would seem ridiculous if we had to lay off a thrashing crew for several days in order to get permission from the State Board of Control to buy a part for a gas engine or a separator … I suspect that the author of the bill had in mind … central purchasing … for stationary, office supplies and office equipment and furniture … but we most seriously object to buying <u>farm</u> supplies and equipment in that manner …*"

One issue that incensed Dave Stephens was the proposal (July 7, 1920) of the Sherman County Court and the State Highway Commission to realign the Moro-Lone Rock Road from the south side of the Station's buildings to an alignment that would be to the north (down slope) of the buildings and corrals. The proposed alignment would go between the Station's central facilities and all of its fields. This issue went unresolved for many years. On March 6, 1925, Stephens sent a letter to Governor Walter M. Pierce, in Salem "*A rather important matter affecting the work of this Branch Station has recently come up here and I am writing you to ask you to help us protect the interests of the State*." "*A new market road is being built into the town of Moro … and in order to get a slightly more favorable grade, there is a disposition on the part of some people, including the County Road Master, to run this road through the Station property, cutting off the buildings and farmstead from the rest of the field and going through some land now used for experimental work. Because I believe that an entirely satisfactory grade can be established for this road without its going through Station property, I am … asking you … to … ask them not to make any decision … until we have had a chance to explain the whole situation to them*."

On March 25, 1925, he sent a letter on the same topic to Carleton Ball, Cerealist-in-Charge of Grain Investigations, USDA-BPI, Washington, D.C. "*A matter of some importance in connection with the work of this station has recently come up on which I would like to get the benefit of your advice. There is being built into the town of Moro from the east, a market road. The engineers claim that in order to get a grade of seven percent of less down the station hill, it will be necessary to locate the road just north of the station barn and buildings, thus cutting off the barnyard and farmstead from the rest of the station farm. I believe that this road location would seriously interfere with our work and I am doing what I can to keep the road off station property but it is difficult to convince the engineers that there is anything so important as grade. In fact, there is a ruling by the highway commission that no state money can be spent on market roads in this state if the grade exceeds six percent. There is a way out of the situation by having the state build the market road to the city limits and having the county or city improve the present road down the hill. The hill, however, can not be made less than eight and one-half percent grade without the expenditure of quite a sum of money. I am wondering just how far we should go in objecting to this road location and whether it* *might be advisable for you or the Secretary of Agriculture* [William Jardine, a close friend of Dave Stephens] *to write a letter to the Governor suggesting that nothing should be done to interfere with the cooperative experimental work of the station at Moro as it might endanger the federal appropriation to this station if the work is in any way hampered. ...*"

A month after the previous letters were sent, Stephens wrote another letter on the same topic to an attorney in Portland. In that letter he also enclosed a sketch to help explain why the Station would be badly served by the proposed realignment of the Moro-Lone Rock Road. The USDA did wade into the fray, as did William Kerr (President of Oregon State College), James Jardine (Director of the OAES), and the State Board of Regents. This highly contentious issue was ultimately resolved when Oregon's Attorney General sent notice of his legal decision to Kerr and Jardine. The Attorney General concluded his finding by stating that "*It is clear, therefore, that the city of Moro has no authority to take this proceeding against the State of Oregon under its Charter. … I would, therefore, advise that the proper officers of said city be informed of this fact. … If desired I will be willing to send a representative to assist in whatever action is deemed necessary or advisable*."

Establishment of the Oregon Wheat Growers League

The Oregon Wheat Growers League was the nation's first successful and long-lasting commodity organization devoted to the production, transport and marketing of wheat. The League therefore is an important milestone in American agricultural history. The founding of the League was documented in a formal report (Maris, 1926), a review (Rost, 1988), and reflective testimonials by past presidents of the League (Zacharias, 2001).

Role of David Stephens

Credit for organizing the meeting of eastern Oregon farmers on February 11-12, 1926 is often attributed primarily to Frank Ballard (Leader of Agents, OES, Corvallis), E. R. Jackman (Chair of the Farm Crops Department), and Harry Pinkerton (farmer at Moro). While also mentioned for his participation as the secretary of a committee, Dave Stephens, Superintendent of the Sherman Station, has not received adequate recognition as one of the most influential key organizers and coordinators of that meeting. Stephens' role deserves and will be given greater definition and elaboration in relation to the focus of this book. Rost (1988) indicated that Stephens and Pinkerton drove together to an organizing committee meeting at Arlington on December 30, 1925. The organization of that coordinating committee had been formalized two months earlier. Stephens' personal collection of letters included a 1-page memo, dated October 29, 1925, from Paul V. Maris, Director of Extension at Oregon Agricultural College, which stated "*The above group is asked to meet at the Imperial Hotel Tuesday evening November 3, at 7:30, for the purpose of developing plans for the proposed economic conference of wheat, to include our Eastern Oregon wheat producing territory*." "*Practically all of those addressed are* [already] *familiar with the idea as it has been discussed.* [The meeting] *will enable us to reach an agreement on time, place, committee organization and tentative consideration can be given to committee personnel*." "*… the plan will be for Mr. Jackman to … assume charge of field organizational work*." The 12 recipients of this memo were G. R. Hyslop, D. E. Stephens, F. L. Ballard, C. J. Hurd, E. R. Jackman, Fred Bennion, R. W. Morse, C. W. Daigh, H. G. Avery, L. R. Breithaupt, Paul Carpenter, and W. B. Tucker. At that meeting it was determined that Stephens would serve as the General Secretary for the meeting. Stephens provided Extension Service letterhead and stenographer services for letters being sent by Harry Pinkerton, who was charged with lining up and organizing the committee chairs.

On December 5, Dave Stephens received a 2-page letter from Oregon's Governor, Walter M. Pierce, in which it was stated "*My dear Friend: I shall be delighted to speak at Moro on state affairs before your Community Club, and will be glad to make a special trip in order to do so." "... I know that I have real friends in the Moro community." "... I could deliver a real address on state affairs, including roads, the penitentiary, and taxes." "... I thank you, dear friend, for your kind invitation.*" Stephens was clearly coordinating the participation of state and federal political leaders. One month later, Stephens continued to encourage colleagues in Washington, D.C. to send a representative from the Office of Cereal Investigations. Stephens had already secured a commitment from the Bureau of Agriculture and Economics; Mr. William Jasper Spillman, a renowned wheat geneticist who was at Washington Agricultural College until 1902, and who had two sisters living in Oregon, at The Dalles and McMinnville. Stephens served as the collector and coordinator of reservations for lodging as well as for the meeting. One note sent to Stephens by a USDA

Agricultural Statistician indicated "*I am planning on attending the Wheat Conference, and would appreciate having you make me hotel reservations, (Room without bath).*" Throughout January, Stephens received numerous responses from growers he had specifically and individually invited to participate in the meeting. Many handwritten notes of the following type are still available; "*Mr. D.E. Stephens, Moro, Ore. Dear Sir: It is my intention to attend the meeting at Moro and at least four of my neighbors have planned to attend. Yours truly, Chas. B. Cox*" [Heppner].

It was clear that Paul V. Maris, the Director of Extension at Corvallis, also remained closely linked into the planning process. In letters to Stephens, Maris was seeking further assistance in securing the seven typewriters that would be needed by the stenographers at the meeting but which could not be transported from Corvallis. Maris also asked Stephens to develop the final draft of the printed program, to invite administrators from the Port of Portland and other key organizations, to make reservations for those who would travel on the Tourist Sleeper that would be furnished by the Union Pacific Railroad, and to coordinate arrival times for the organizing chairmen and secretaries. Maris also stated he was directing Stephens and the county extension agents "*to work up good sized delegations*" from their counties.

On February 8, E. R. Jackman sent a letter to 10 leaders of the Wheat Conference, including Harry Pinkerton (Moro), D. E. Stephens (Moro), E. M. Hulden (Blalock), R. W. Morse (Heppner), A. R. Shumway (Milton), L. R. Breithaupt (Corvallis), F. B. Ingels (Dufur), G. H. Hyslop (Corvallis), L. Barnum (The Dalles), and Fred Bennion (Pendleton). Included in the letter were the following: "*Gentlemen: Mr. Stephens has suggested that it would work to the advantage of the Wheat Conference if all of the chairmen and secretaries could meet at Moro the evening of the day before the conference … so that the group meetings will run more smoothly … and give each group a chance to see what subjects other groups will consider. If we can all be at Moro by 6:00 we can eat dinner together and then have the meeting immediately afterward*."

On February 16, Dave Stephens wrote a 2-page typed letter to his close friend, William Jardine, the Dean of Agriculture at Kansas Agricultural College. The letter included the following. "*Dear Will: We have just finished quite an ambitious undertaking – an Economic Wheat Conference – in this state. It was very good. I am inclosing a program which will give you an idea of how the problems were attacked. The findings will be published.*" "*I am* [also] *inclosing an editorial from the Oregonian with reference to a new organization of wheat growers which was started as a result of this Conference.*" "*The conference, of course, was an Extension Service affair, but Professor Hyslop and I saw to it that the Experiment Stations received proper advertising*." A few days later, Extension Director Maris wrote a 2-page typed letter to O.A.C. President William J Kerr, which included the statements "*I have just returned to the campus after attending the Wheat Growers Economic Conference held at Moro. … I believe… the conference has been the largest and most successful off-campus undertaking of the College during the ten years that I have been in the State. We had present the leading men of Eastern Oregon and there were many evidences of appreciation of the service rendered by the College. The work of certain members of the staff … deserves special mention*:" The letter continues with special accolades for the supervision provided by E. R. Jackman, for the work of Dave Stephens and the Moro Experiment Station, the contributions of Professor Hyslop, the press service coordinated by Mr. Kadderly and Mr. Burtner, "*the county agents of the wheat counties*", and the participation by leaders of various state and federal organizations.

It was largely through Stephens' leadership as the General Secretary for the Wheat Growers Economic Conference, and to his organizational skills, connections, influence, and support services, that the full report of that meeting was published under the name of Paul Maris, Director of the Extension Service at Oregon State College (Maris, 1926). That report greatly under-represented the immensity of Dave Stephens role in providing overall coordination for that publication, including much of the text, the organization, and details regarding specific farming practices, grain production, and grain marketing data in the report. David Stephens and the Sherman Station were by all measures deeply contributory to the meeting that led to establishment of the Oregon Wheat Growers League.

Role of Weather

Recent references indicate that the hard winter of 1924-1925 was an important factor leading to the formation of the League during a meeting of growers during February 11-12, 1926. However, an examination of annual reports from the Sherman Station and letters from the personal collection of David Stephens suggests that other factors were even more important for the development of that meeting. During the early and mid-1920s, the livelihoods of wheat growers were stressed by low wheat prices and severe anomalies in seasonal amounts and distributions of rainfall. Additionally, there was a severe drought that affected the 1924 wheat crop. The crop-year precipitation at Moro for the 1924 crop was only 7.7 inches, which caused significant reductions in yield. Also, the common bunt disease greatly reduced profitability during those years. David Stephens estimated the financial losses from common bunt for the 1923 crop year (see Chapter 20). The losses to Oregon farmers was estimated to be $1,694,202 and the losses to farmers in all three Pacific Northwest states was $7,499,628. The losses were caused by reduced grain yields and, more importantly, by price dockages and lower market grades that were applied to nearly two-thirds (62 percent) of the grain shipments in 1925. These impacts on grower's income were at least as influential, and probably moreso, than the deep freeze without snow cover during December 1924. That freeze killed all winter wheat on the Sherman Station (see Chapter 4), and at six of the eight off-station cereal nurseries, including nurseries at Lexington, Eightmile (in Morrow County), Condon, Kent, Prineville and Friend (in Wasco County). In fact, complete killing occurred at all nursery locations except at Pendleton and Dufur. Except for parts of Umatilla and Wasco counties, all fields in all Columbia Basin counties had to be totally reseeded. Astoundingly, then-recent date-of-planting studies at the Sherman Station had shown that winter wheat could be planted as late as February 15 and still produce yields equal to or better than spring varieties. Most fields were therefore replanted to winter wheat during late January and early February. Good weather during the spring growing season, and more than 2.2 inches of rain over a 5-day period in May led to a very productive year for the replanted winter wheat as well as the spring cereals. The need to replant certainly imposed additional expense, but there was no similar ability for farmers to partially recover from other constraints that had been reducing profitability.

Rost (1988) referred to the devastating winter of 1924-1925 as one of the primary stimuli leading to the gathering of farmers that resulted in the founding of the Oregon Wheat Growers League. However, Rost's own statements indicated that the freeze was not among the issues stated by a primary organizer of that meeting. Rost's examination of personal records of Mr. Harry Pinkerton (a Moro-based wheat farmer who had been asked by the Oregon Agricultural College to serve as chairman for the meeting) led to his statement "… *Pinkerton mentioned two of the three forces responsible for the League's formation. The first was Oregon Agricultural College (actually the O.A.C. Extension Service), and the other, Governor Walter Marcus Pierce. The third, not mentioned by Pinkerton, was a colder-than-usual winter storm (the winter freeze of 1924) that occurred a little over a year before the conference. The Extension Service, Pierce, and the storm united the growers, not as farmers, but as wheat producers of eastern Oregon, giving them an identity based on the region where they lived and the commodity they produced. The storm brought a disaster that forced the growers into action; Pierce rewarded their united efforts; and the Extension Service provided an opportunity for the growers to remain united in a new kind of organization*." Rost went on to state that the League was organized in 1926 because the wheat grower's "*needs had grown painfully over the previous five years, as a sagging agricultural economy in the United States began smothering the eastern Oregon wheat trade*." This was acutely pointed out by another passage, in which Rost revealed the following passage in Pinkerton's personal notes: "*However, in the early 1920s many eastern Oregon wheat growers …became caught in a cost-price squeeze – production costs remained high, while cash returns from crop sales sank lower and lower. In a diary entry dated March 24, 1921, Pinkerton wrote 'Got letter from banker demanding us to sell our wheat. Wheat at lowest figure in last eight years. On March 29, he wrote 'Pa and I sold our wheat. I got $1.05 per bushel for 59 test wheat. Cost $1.75 per bushel to raise it.'* "

In a reflection of information already presented by Rost, Zacharias (2001) re-stated that "*It was these men* [Jackman, Stephens, and Ballard, all of whom were on the faculty of Oregon Agricultural College] *that many farmers sought out when they were threatened with a crop failure by a devastating freeze in December 1924*." "*An economic conference planned by the Extension Service in the spring of 1926 received heightened interest among the agricultural community after they were credited with saving the 1925 harvest crop*." While humbling, that most recent portrayal of winter freeze being a primary factor that led to organization of the growers was greatly over-simplified.

Contributions to Science

Dave Stephens was at the forefront of scientific procedures applied to agricultural research. As one example, he was an early adopter of replicated plots to examine effects of treatments in experiments. The original experiments established at the Sherman Station were not replicated except in time, over years. The following was taken from a 2-page letter to Dave Stephen from T.D. Farrell, at Aberdeen, Idaho. The letter was dated March 8, 1913. "*The main thing that … this study has emphasized in my mind is the absolute necessity of conducting experiments in multiplicate. Accidental errors are so great that single plat results are worth little or nothing, where the yield variations are as small as they ordinarily are. The majority of our cultural and similar experiments are now run in duplicate or triplicate and some of them are repeated as many as five times. This method … is incomparably better than the old method, where only single plats were grown*." This letter signified the beginning of an evolution from non-replicated to replicated treatments within experiments. Replicated treatments could be subjected to statistical analysis but the non-replicated plots could not, at that time, be analyzed for significance.

Collaborations

Staff of the dryland stations have always collaborated with local as well as regional and international colleagues. Some of the national and international collaborations were with other agencies, such as the Soil Conservation Service, or scientists at many other universities and federal agencies in this country and overseas.

Examples of scientific equipment used at the Sherman Station during its' early years
(now on display at Sherman County Historical Museum)

Dave Stephens was an especially active writer of letters. It was common for him to type letters that were 2- to 5-pages in length. He communicated with county agents and scientists in California, Utah, Nevada, Idaho, Washington, Montana, Nebraska, Kansas, and others. In Oregon, Stephens was especially communicative with agents in Harney, Malheur, Klamath, Lake, Wheeler, Jefferson, Wasco, Sherman, Gilliam, Morrow, Umatilla and Union counties. He also exchanged seeds with scientists or seed merchants in Argentina, Turkey, Spain, Romania, Nicaragua, Australia, China, Peru, Mexico, South Africa, and perhaps other nations. Stephens was also among the superintendents who were active in their professional societies. For instance, Stephens was President of the Western Section of the American Society of Agronomy in 1927 and he hosted a meeting of that Section at Moro on June 27-29, 1927. Stephens was also invited to present exhibits at numerous county fairs and the State fair. All station scientists regularly presented invited speeches at a wide variety of educational meetings sponsored by agribusiness, extension agents or specialists, and other private or public institutions.

Another example of collaborations is depicted in a 2-page letter from Stephens to Mr. F. B. O'Grady, Buenos Aires, South America, dated November 3, 1928. "*Dr. Mr. O'Grady: The seed grain ordered by you was forwarded to the McCormick Steamship Co. and should be on its way to South America by this time. I trust it arrives in good condition. I received a telegram today that they* [Fireman's Fund Insurance Co.] *were sending me a check*." The letter goes on to convey information about the shipment of 110 bags of seed. Most of the seed was purchased from farmers but some was grown at the Sherman Station. The shipment included Markton oats (14 bags), Oro winter wheat (25 bags), Federation spring wheat (14 bags), Hybrid 128 winter club wheat (14 bags), O'Rourke field peas (9 bags), Trebi barley (14 bags), and Hannchen barley (14 bags). The Trebi barley in the shipment was purchased from the USDA at Aberdeen, Idaho, and shipped to Moro, to be included in the export shipment. It is still common for scientists to send or receive seed with special attributes from different countries. During the first five decades, the Station at Moro was considered a key focal point for dryland cropping scientists across the U.S. and internationally.

Contributions to Community

The administrators and all other staff members of both dryland stations have been deeply involved in the Moro and Sherman County communities. This was particularly true for those who resided at the Station and therefore became part of the fabric of the local community. Some of these relationships are well documented and worthy of sharing with readers who may not be aware of those interactions.

David and Kate Stephens and their four children (Edmund, Thomas, Emmajean, and Janet) became fully integrated into the local community from 1912 until 1938. Dave served on many local committees. One of the first documented activities occurred in 1914, when he scripted a letter on August 16 to the Lee P. Ketchum Coal Company in Seattle. This letter clearly indicated that Stephens coordinated the purchase and delivery of about 50 tons of coal from a mine in either Wyoming or Montana. The coal was to be divided among 22 local farmers and businesses that participated in the order. He ordered a shipment of 97,998 pounds and consolidated the receipts from others to make single payments to the railroad agent (for freight charges) and the coal supplier.

On May 6, 1917, in a 3-page letter and list from Fred Pickett, Chairman of the Clean-Up Day declared by Mayor Thompson, of Moro it was stated that "*Each male resident is urged to report at 7:30 a.m. to the respective committees upon which they are named, fully equipped with the necessary implements of warfare in waging the fight against dirt. A list of the committees and the territories which they are expected to clean up follows*:" Eleven committees were named, including one that included staff at the Experiment Station. The committee for "*South of Railroad*" included "*D. E. Stephens, Captain, M. M. Oveson, Foster Martin, Bob Hoskinson, W. H. Ragsdale, Chas. Montgomery, Everett Hastings, F. D. Flatt, and D. W. Nish.*"

Stephens also provided testimony for several local farmers who desired to produce wheat rather than be conscripted into overseas duty during World War I. On August 9, 1917, Stephens wrote to the Draft Board: "*This is to certify that I have known Mr. Omer G. Sayrs since the spring of 1912. I am glad to state that he is one of the very best farmers in this section*." The letter goes into details regarding the acreage farmed and the amount of grain and livestock produced. It continues, "*With the help of only one man, Mr. Sayrs has been operating this large farm with wonderful success. His wheat yields are always among the very highest obtained in this County. ... Considering the present shortage in the world's food supply, I would deem it very unfortunate if Mr. Sayrs would be compelled to leave his farm. It would be practically impossible to get another man to run this farm without seriously diminishing its returns.*"

While working at the Sherman Station, George Mitchell married Gwendolyn Reese on June 14, 1925, at the Thomas and Alma Reese home at Monkland, in Sherman County (Sherman County 'For the Record'; 1992, Vol. 10, No. 2, page 54). Two years after George and Gwen were married, their first daughter (Mary Ann) was born at Moro. A second daughter (Carol), was born in 1948, the year the family moved to the Pendleton Station. The Stephens' daughter, Emmajean, married Karl Peterson at the Station residence on August 4, 1935 (Sherman County 'For the Record'; 1993, Vol. 11, No. 1, page 54). At least one other marriage occurred in the Station residence. That occurred after the Mitchell family returned to Moro. On June 14, 1953, Carol Jane Mitchell married Michael Orlando "*in the home of George Mitchell, Moro*" (Sherman County 'For the Record'; 1994, Vol. 12, No. 1, page 58).

Similar details could be provided for the Oveson (1938-1948), Hall (1953-1964) and McDermid (1964-1973) families. Merrill and Mal Oveson raised four children and Bill and Dorene Hall raised two children in the Moro community. The following statement encapsulates a part of the lives of those families: "*During the depression years we didn't have money for entertainment but that didn't mean we had none! We made our own … Some young couples included … Merrill and Mal Oveson (experiment station)…*"…"*These were enjoyable years living in a small town where we knew everybody*." Those remarks were from an article entitled "*Memories of a Bride in the Depression Years*," and printed in the Sherman County 'For the Record' (1989, Vol. 7, No. 16, pages 15-18).

Bill and Dorene Hall moved to Moro during 1947 and lived there for the next 17 years, with the exception of a short stint while Bill was at school in Corvallis. Upon first arriving, they and their two children briefly resided in the Moro Hotel. From that location they witnessed the fire that totally destroyed the Oveson's house on the Station (Hall, 1997). The Halls then renovated and moved into a house near the school in Moro. Oveson was transferred to Pendleton before the new house was completed during the spring of 1949. The Mitchell family became the first occupants of the new house when they returned to the Sherman Station in 1949. Mitchell resigned in 1953 and Bill Hall became Superintendent of the Station. The Hall family occupied the new house starting in 1953. That move enabled the Hall's four children to start raising animals for their 4-H projects. As with their predecessors, the Hall family became deeply involved in the community. Bill Hall also served as a mayor of Moro, a member of the budget committee, and a volunteer fireman.

When Bill Hall became Superintendent he immediately began to upgrade the old farm and experimental equipment. The tongues on that equipment had been modified in 1948 so they could be pulled by a tractor rather than by horses. Hall made arrangements to lease new field equipment from several manufacturers for a period of 10 years. The suppliers rotated their equipment every three years as an opportunity to display their newest equipment to potential buyers in the area. After leaving the Station in 1964, Hall earned a Ph.D. degree and worked for universities and agencies to improve agricultural production in at least nine countries, all except one of which were in Africa.

Establishment of Other Stations

The Sherman Station had both negative and positive influences on the establishment of other branch experiment stations. Three examples include experiment stations in Morrow and Umatilla counties of Oregon, and in Adams County, Washington.

Morrow County

In 1910 it was proposed that an experiment station be established in Morrow County but the proposal was blocked by a gubernatorial veto. The Salem Daily Capital Journal, on page 6 of the February 23, 1911, printed a sub-headline "*Morrow Looses Experiment Station*" in an article with the main headline of "*His Veto Hatchet.*" The article stated "*Because he felt that the territory in and around Morrow County is being taken care of by the Sherman county experiment station, the governor vetoed house bill No. 343, which provided for the creation of an experiment station in Morrow county. It carried an appropriation of $3,550.*" The recently established 'Eastern Oregon Dry-Farming Substation' had clearly become a priority of the Governor, in that he expected the existing station to serve the needs of farmers throughout the low-rainfall region.

Adams County, WA

The Sherman Station served as a 'template' for establishing an experiment station near Lind, Washington. That station is now known as the Lind Dryland Research Center. It was initially established on 320 acres of land deeded to the Washington Agricultural Experiment Station by Adams County on April 1, 1915. That station was established less than a year after Ira D. Cardiff, Director of the Agricultural Experiment Station in Washington, wrote a letter, dated March 9, 1914, to David Stephens, Superintendent of the Eastern Oregon Dry-Farming Substation. The letter included the following: "*My dear Mr. Stephens: Having heard considerable of your work in dry land experiments, I am desirous of visiting your station some time in the not very distant future, perhaps in company with one or more members of my staff." ... "whether you could give us a little of your time in showing your experiments and in discussing them with us. Ira D. Cardiff"* Stephens responded positively and the Dryland Experiment Station at Lind, WA was established less than a year after Dr. Cardiff and others visited the Sherman Station. Initially, the station at Lind directly paralleled the one at Moro, including the principal focus of its research, the types of buildings that were constructed, and the equipment purchased. More recently, in 1997, the Washington State Legislature added another 1,000 acres to the land administered by that station. Today, the Lind Dryland Research Center places a much higher emphasis on wheat breeding, pest management, tillage management, and moisture conservation than occurs at the Sherman Station.

Umatilla County

When another Oregon dryland experiment station was considered for establishment in an area of higher-precipitation, the Sherman Station again had a very strong influence. Discussions were held with the Umatilla County Agent, Fred Bennion, who had been conducting collaborative experiments with the Sherman Station throughout the 1920s. Discussions also included representatives of the Confederated Tribes of the Umatilla Indian Reservation. Dave Stephens was highly influential in these discussions and ultimately became the Superintendent of the station constructed northeast of Pendleton. Insights into those formative discussions are presented in Chapter 3; Establishment of the Pendleton Station.

Other Topics

Dave Stephens often had in-depth communications with a number of people in influential positions. Some of those communications were amiable and forward thinking, and other communications dealt with contentious issues. A few examples from each of these situations are provided to reveal the amount of time and energy that Stephens spent on issues other than the agronomics and business aspects of the dryland station.

Future of Wheat Production

William M. Jardine was, at that time, the Dean of Agriculture and the Director of the Kansas Agricultural Experiment Station, at Manhattan, Kansas. Jardine was also a former colleague of Stephens when they both worked at the USDA-BPI in Washington, D.C. During the mid-1920s, Jardine became a member of the U.S. President's Commission on Agriculture, and later became the Secretary of Agriculture.

In a 5-page letter from Stephens to Jardine during the deep freeze of 1924, dated December 30, 1924, Stephens stated that "*Another favorite topic among statesmen and would-be statesmen is that of cooperation. Many people believe that cooperative marketing is to be the solution of all our price problems. Several years ago the farmers of the Northwest plunged into a wheat marketing organization, signing up its members for six years, according to the "Sapiro Plan." The undertaking has ended in dismal failure. The idea of further legislation to encourage cooperative marketing will not meet with much enthusiastic approval among farmers of the Northwest*." That short clause was but a short part of Stephen's reactions to many national and local questions and issues being asked of him as Jardine prepared to represent views from the Pacific Northwest during meetings of the Agricultural Commission in Washington, D.C. However, other issues in Stephen's lengthy letter provided even greater insights into the legendary thinking of Superintendent Stephens. Other excerpts from the letter include the following. "*Farmers thus far … have been concerned only with getting high-yielding wheat varieties*." "*The price of our wheat, therefore, is likely always to be governed by the export demand and will have to compete in Orient and European markets with southern hemisphere grown wheat*." "*… While it is true that we can and should diversify more, especially in some of the higher-rainfall sections of the Northwest, the fact remains that the number of crops that we can profitably grow on our lands is exceedingly limited and none are so productive or desirable, everything considered, as the small grains. We may at some future date grow a somewhat greater diversity of crops, but our basic industry will likely always be wheat-raising. So whenever we are unable to raise wheat profitably we shall have hard times. And with present high costs, the farmer of the Northwest cannot get by with a price much less than a $1.25 a bushel for his wheat*." "*… any recommendation for legislation encouraging greater crop diversification will be largely futile, so far as the Northwest is concerned. On our dry lands, most of which gets less than 11 inches of precipitation annually, very much diversification is entirely out of the question.*"

"*Your suggestion regarding the possibility of increasing the consumption of wheat and wheat products in the Orient is good. I have often thought that if only a very small percentage of the population of China and Japan could be educated into eating wheat products it might materially increase consumption and reflect on wheat prices*."

'Minor' Inconvenience

It was also common for Stephens and other Superintendents to alter their focus from the immediate needs of the Station to deal with requests by administrators. As an example, on July 14, 1922, James Jardine, Director of the OAES, sent a note to Stephens during the time they were harvesting experiments on the Station and at off-station nurseries. Jardine's letter stated "*… The Board of Regents voted to have a* *committee visit the Moro Station … at once. President Weatherford will stop in Moro on Monday enroute to Nevada by automobile. Senator Pierce, Mr. Hawley, Mr. Spence and Mr. Woodcock have agreed to meet with me at The Dalles for early breakfast next Thursday morning, July 20. They desire to arrange for an automobile to take the 5 passengers from The Dalles to the Moro Station early in the morning and return in the evening. I know that you are going to be busy but the visit is important even though several of the men have been at the Station a number of times. … The desire was expressed to meet people and get the sentiment. …* [Please] *arrange for an automobile to carry 5 passengers from The Dalles to Moro*." "*… The Board members are busy and the arrangement … will save them a day of train travel. I should like them to put in a real day, about half in the field and about half going over the charts and results and publications in the office. Will you let me hear from you at once*?"

Drawing a Line in the Sand

During the early years, it was also common for administrators at Corvallis and Washington, D. C. to assign time-consuming or expensive projects to the branch experiment stations. This was sometimes based upon issues that an administrator considered important for the industry, but it was just as common for an administrator to make a commitment of the experiment station to satisfy a political obligation. In late October of 1913, Stephens received a letter of the latter type from Henry Scudder. The letter, in part, stated that "*I forgot an important item in my letter this morning. The Plateau Farming Company have on their farms in Gilliam County about 100 acres of alfalfa which was seeded in rows in 1912. They cut this for seed this summer, but were unable to thresh it out with the large machine which they use with their grain. It is very important, indeed, to our work in the dry farming section that we demonstrate the alfalfa to be a success as a seed crop, as you understand. Now, … we ought to get this threshed out for them …*" "*… I have told them that I would … get you to go up to Gilliam County with the station threshing machine and thresh out their crop*."

The following day, on October 24, Dave Stephens responded by stating that "*I think it would be exceedingly inadvisable to take our outfit up there to do the work and I am sorry you mentioned the matter to any member of the Company. From 100 acres of alfalfa they probably have from sixty to seventy ordinary wagon loads of stuff to run through the machine. Six or seven of these would be a big day's run with our small outfit, so it would probably take us about two weeks to do the work. We have about all we can look after here without tackling as big a job as that. I regret very much that the Company may have to lose this seed, but it seems to me that the threshing proposition should have been investigated before planting such a large area for seed…*" "*… you have therefore asked us to do about $500 worth of work for the Plateau Company. It is of course impossible for us to even consider such a proposition*." The letter goes on to explain difficulties in shipping the equipment to Gilliam County by a freight hauler, and the likelihood for interruptions by rainfall at that time of the year. He also explained that alfalfa seed could not be threshed if gets damp or too humid. Stephens concluded with "*… we shall have to refuse to do the work. I am very sorry, indeed ….*"

Scudder immediately retorted by ordering Stephens to ship the equipment and stated that "*they will let you know when it arrives so that you can go up there immediately. The matter of the alfalfa threshing in Gilliam County must not be neglected as it is very important to us. I would really hardly feel that it is advisable for you to leave* [go to Washington, D.C. to do the required writing of the Station's Annual Report] *without giving that matter immediate attention. … I really feel that it is work you should do anyhow. I do not want to interfere with your plans or inconvenience you in any way, Stephens, but I really don't think that it would be policy for you to go* [to Washington, D. C.] *until everything is finished up that should be attended to*."

Instead of responding to Scudder, Dave Stephens sent a letter, dated October 26, 1913, to the Plateau Farm Company, stating that "*Almost any kind of machine can be made to do the work, though any of them will do the work rather imperfectly. I am sure there are a half dozen threshing outfits in your locality than can thresh alfalfa seed as well as our outfit can and do the work much more quickly. If impossible to get the work done this fall, I would suggest that the seed be put in neat stacks with straw on top to stop it from getting wet, and it will keep perfectly until next season. … in the meantime … you can purchase equipment … to thresh alfalfa seed. With our seed* [on the Sherman Station] *we thresh the seed and … about twice through our 'Clipper' cleaner, … cleans it thoroughly*." Then, two days later, Stephens also responded to Scudders. He wrote "*Dear Professor Scudder: Just received your letter. I am convinced that you are exceedingly overworked and possibly somewhat irritated … Take a vacation for a few days and come up* *here for a rest. I think I can easily convince you that the sending of our outfit up there is extremely unwise and unnecessary. … I hope to get off for that 'vacation' in Washington as soon after the first as possible. I'll be on the job every day writing up results and learning how to better run this Eastern Oregon Dry Farming Substation*."

Before departing for Washington, D.C., Stephens wrote a 2-page letter to his direct supervisor at Corvallis, Dr. James Withycombe, Director of the Agricultural Experiment Station. He stated "*For the first time, Professor Scudder and I have failed to agree on a proposition concerning our work here, and I have thought that the proper procedure would be to refer the matter to you for your opinion. I am therefore sending you all the correspondence with reference to our threshing some alfalfa seed for the Plateau Farm Company in Gilliam Co. I would like you … to read these letters, confer with Prof. Scudder …, and then write me whether you think it advisable for us to proceed as he suggests in his letters. … my reasons why I think it inadvisable for us to do the work, are as follows*:" He then listed six reasons. "*1. Our little thresher is not equipped for threshing alfalfa seed and … will … do the work no better than the threshers they are using in Gilliam Co.; 2. Their representatives visited the station this summer and knew that we were raising alfalfa seed. Their asking us to do this work for them at this late date, I think is unreasonable, to say the least; 3. This is the rainy season … and their would undoubtedly be … days and possibly weeks, when it would be impossible to thrash alfalfa seed; 4. We consider it our duty to help farmers in every way possible … but I think it is not within our province to actually do their work for them, and this work would be a bad precedent to establish; 5. From a statement in Prof. Scudder's letters, I judge that he had forgotten that we now have grown on the station more than six acres of alfalfa* [under different planting and management conditions, and harvests both for forage and seed] *and we shall be able to tell whether alfalfa growing can be made a profitable business on the dry uplands of this section of the State. The information that the Station might get from the yields of the Plateau Farm Company's alfalfa seed, is, I think, entirely out of proportion to the expense incident to our threshing their seed; 6. Though our crops are harvested and our fall seeding completed, we have by no means finished our work. There is … fall plowing, weeds to be gathered and burned, corn to be husked, etc. To do this work in Gilliam County would seriously interfere with our work. It would mean more than three days for several of our staff, shipment of our separator and also our six-horsepower gasoline engine. I had planned to leave for Washington* [D.C.] *sometime next week to begin work on the annual report,* [but] *I shall be glad to remain here if you think it is important that we do this threshing work. I shall be glad to have your decision by wire*." Withycombe responded by telling Stephens to have a good trip to Washington, and that he looked forward to getting a copy of the annual report.

Pendleton Station

Staff at the Pendleton Station have also made exceptional contributions to their community and to science. Various aspects of these influences are discussed.

All administrators of the Oregon State University programs at Pendleton Station have been members of the Pendleton Rotary Club, the oldest service club in Pendleton. This series began with George Mitchell during the 1930s and continued with Merrill Oveson, Charles Rohde, Steve Lund, Richard Smiley, Steve Petrie, Valcho Jeliazkov, and Mary Corp. Also, several administrators of the USDA programs at the Pendleton Station were members of Rotary, including Bob Ramig, Betty Klepper and Dale Wilkins. Perhaps the greatest contributions to that organization were from Merrill Oveson and Richard Smiley. One of Oveson's roles in Rotary, as coordinator of the Fat Stock Sale, was described in Chapter 23. Smiley served for several decades on the Board of Directors, and also served as president, historian, and a coordinator of many club committees and activities.

In 1946, George Mitchell and his wife, Gwendolyn, were each deeply involved in Umatilla County's Agricultural Planning Conference (Terjeson and Johnson, 1947). They were members of four of the nine committees that met at least three times during 1946. That process was consummated when the committee reports were accepted and formally adopted when all committees met for a final Planning Conference on January 23, 1947. George Mitchell clearly provided a great amount of input to reports of the Land-Use, Soil Conservation and Crops committees. Gwendolyn also contributed to the report of the Farm Home and Rural Life Committee. During World War II, each of the Mitchell's served formal appointments on locally-based national emergency committees such as the War Rationing Committee. George Mitchell was a charter member of the Oregon Wheat Growers League and a member of organizations such as Rotary Club, Elks Club and Masonic Lodge. The Oregon State Farm Bureau recognized his service to agriculture by awarding him a distinguished service award.

Gwendolyn Mitchell became very involved in local and state politics, particularly after her husband retired from university service. When she was about 65 years old, Gwen Mitchell became the first person east of the Cascade Mountains to serve as the hostess for the Oregon Legislature in Salem, an appointment she held for three consecutive terms over a six-year term. When in her mid-80s, she served on the Oregon State Board of Transportation, where she was became an especially strong advocate for providing buses for senior citizens in communities that did not have public transportation. She continued to participate in annual field days at the Pendleton Station until she was about 90 years old. At that same age, she was still an active daily participant in community programs such as Senior Companion and Foster Grandparents. She became one of only three dozen individuals (at that time) to receive an award for outstanding contributions to agriculture, the Oregon State University College of Agricultural Sciences Diamond Pioneer Agricultural Career Achievement Registry. In 1987, at age 85, Gwen Mitchell was an invited guest to the inauguration of State Governor Neil Goldschmidt.

Contributions to Science

Each of the scientists at the Pendleton Station have made important contributions to science. Those contributions and influences are too numerous to encapsulate in this chapter. Therefore, an overview of contributions of just two recent scientists were selected to exemplify this activity from the Pendleton Station, based entirely upon the authors knowledge and insights. Dr. Betty Klepper was a former Research Leader of the USDA-ARS unit at Pendleton, and Dr. Richard Smiley was a former Director of the OSU Columbia Basin Agricultural Research Center, with stations at Pendleton and Moro.

Drs. Klepper and Smiley had polar-opposite backgrounds prior to serving as scientists and administrators at Pendleton. She was the relatively-privileged daughter of a lawyer and a high school teacher in Tennessee. He was the son of a lower-wage employee of farms and ranches in central California. Betty graduated from elite private schools and universities, where her majors were chemistry, physics and botany. Richard attended high schools in three different small towns and cities, and worked while attending state colleges and universities. His majors were soil science and plant pathology. Klepper and Smiley both conducted post-doctoral research in Australia. She then became an Assistant Professor of Agronomy at Auburn University. He became a plant pathologist and advanced through the professorial ranks at Cornell University. Dr. Klepper conducted research on interactions between plant root systems and soil, before moving to Richland, WA, where she was a plant ecologist at the US Department of Energy's Pacific Northwest National Laboratory, formerly Battelle Northwest Laboratories. Her research in Washington was on pristine natural habitats of arid landscapes at the Hanford Nuclear Reservation. She moved to Pendleton, where she became a USDA-ARS plant physiologist at the Columbia Plateau Conservation Research Center. Dr. Smiley became a world authority on the biology and control of root-disease complexes of grasses on golf courses, sod farms, cemeteries, home lawns and commercial landscapes. He then became a plant pathologist at the Columbia Basin Agricultural Research Center, at Pendleton.

Drs. Richard Smiley and Betty Klepper, with Marilyn Smiley (2010)

In 1985, Klepper and Smiley became administrators of their respective agencies at the Pendleton Station, and became recognized for fostering greater levels of research productivity and of harmony and collaborations among employees of the two agencies at Pendleton. They were each inducted into the Diamond Pioneer Agricultural Career Achievement Registry, a recognition bestowed by the College of Agricultural Sciences at Oregon State University.

Dr. Elizabeth Klepper

During her 20 years of research at Pendleton, Dr. Klepper authored or co-authored 243 publications, including 34 book chapters, 74 refereed journal articles, and 135 other technical and extension papers. She was particularly well recognized for her research on plant development, and for leading a team of soil physicists and mathematicians who became internationally renowned for developing a predictive model that described details of developmental processes for wheat shoots and roots, from the time of planting seed until grain is harvested. This ground-breaking research contributed immensely to the understanding of wheat and grassy weed development and to the interpretation of stresses and anomalies that may have occurred during the plant's life. Other scientists, extensionists, farmers and corporate agronomists heralded her research as "pushing the frontiers of wheat breeding in the Pacific Northwest."

Betty Klepper served on the publication editorial boards of five scientific organizations, and as the Editor-in-Chief of one journal. She also served on the Board of Trustees of the Agronomic Science Foundation, and organized and presented teaching workshops for extension educators at universities in Oregon and Washington. She was an evaluator of international research programs in India, evaluated agronomic projects in Africa (for the International Atomic Energy Agency), was a consultant to three Australian laboratories, and evaluated wheat breeding programs in the Republic of South Africa.

Dr. Klepper is one of the few scientists nationally who have been elected as Fellow of each of the three major agronomic societies in the U.S. She was the first woman to be awarded the distinction of Fellow of the Soil Science Society of America, and then she was also named Fellow of the American Society of Agronomy, and Fellow of the Crop Science Society of America. She received numerous other awards that included USDA Scientist of the Year, National Science Foundation Women in Science and Engineering Award, Fellow of the American Society for the Advancement of Science, President of the Crop Science Society of America (the first woman elected to this role), City of Pendleton's Woman of the Year Award, Monsanto Crop Science Distinguished Career Award, Crop Science Society of America's Presidential Award, and others.

Dr. Betty Klepper was one of eight women scientists whose experiences, achievements, wisdom, and philosophies were highlighted in a special publication of the American Society of Agronomy (*A Century of Women in Agronomy*). Lastly, the Crop Science Society of America established the Betty Klepper Endowed Lectureship to stimulate annual scientific discussions of cutting-edge crop science issues, to recognize outstanding scientists, and to honor Betty's scientific and leadership achievements. That lecture is presented by a different scientist every year at the annual meeting of that professional society.

Dr. Richard Smiley

During his 30 years of research at Pendleton, Dr. Smiley authored, co-authored or edited 471 publications, including four books, 31 book chapters, 89 refereed journal articles, 223 other technical publications, and 128 extension publications. He became recognized for his research on the biology and control of fungi and nematodes that cause root- and crown-diseases of field crops in the Pacific Northwest. He developed and maintained collaborations with scientists in about three dozen countries and visited scientists at their workplaces in 16 countries. His technical publications included co-authors from Algeria, Australia, Belgium, China, Germany, Iran, Russia, Scotland, Turkey and the U.S. During about 50 international trips, he visited 35 countries, of which some were visited multiple times; e.g., Australia (8 trips), France (6), Canada (3), China (2), Japan (2), and others. He served on graduate student committees in other states and countries, and has served as a referee for doctoral theses at six overseas universities. Smiley organized regional and international conferences, served on technical committees of professional societies, and collaborated on national and international research projects.

Dr. Smiley served at a high level of leadership in the American Phytopathological Society, including the Financial Advisory Committee and APS Press, the society's book publishing division. APS Press' gross income doubled during each year of Smiley's four-year term as Editor-in-Chief. The English-language edition of a book that he wrote continually sold more volumes than any other book sold by APS Press; more than 50,000 copies were sold. That book was also translated into three other languages, and unknown additional copies were sold overseas.

Richard Smiley was awarded a Post-Doctoral Fellowship by the North Atlantic Treaty Organization and the Briskey Award for Faculty Excellence at Oregon State University. He is a Fellow of the American Phytopathological Society and was a member of six professional societies. He served on the Board of Directors for the International Society of Plant Pathology and the United States Council for Agricultural Science and Technology. Smiley was appointed to small committees of scientists who reviewed and made recommendations for statewide teaching, research and extension programs for plant pathology in the states of Idaho, Florida and Texas. He was the American representative to four international initiatives; a 3-member review team responsible for improving the organizational efficiency of Australian agricultural research institutions, a 3-member review team to guide wheat and barley breeding priorities for research on Fusarium crown rot in Australia, a 10-member Scientific Advisory Board for a Center of Excellence for Plant Protection at 16 member institutions within the European Union, and a 6-member global initiative to improve research efficiency on nematodes that attack small grain crops. In retirement, Smiley continued his international services on a global cereal nematode initiative and on the Expert Working Group for Biotic Stress, which is a sub-unit of the International Wheat Initiative.

Contributions of Other Scientists

The fore-going discussion of contributions to science could be greatly expanded by including similar statements of activities by almost all of the other scientists who have served or are serving at the dryland stations. That discussion would become truly extraordinary and seemingly endless, while also incomplete. Therefore, the two previous examples are used to indicate that scientists at the dryland experiment stations serve an audience in addition to their grower clientele and the communities in which they live.

Collaborations

All of the scientists developed collaborations with other scientists within their area of research interest. Collaborations shown in the preceding section illustrate just a glimpse into the interactions by scientists at the Pendleton Station. Many outside grants have fostered collaborative relationships between scientists and extensionists in different specialty areas, at different institutions, and in different states or countries.

Applied research and extension programs have promoted and encouraged particularly high numbers of collaborations between scientists, growers, industry organizations, manufacturers and suppliers. These are best exemplified by the extensive list of cooperators who participated in applied research and extension programs conducted by Drs. Daniel Ball and Donald Wysocki. Those lists include cooperators throughout the three Pacific Northwest states and beyond, and are too lengthy and detailed to be presented here.

Contributions to Community

The Pendleton Station employees have always been closely involved in their communities. Scientists and staff have lived throughout Umatilla County in the towns of Adams, Athena, Helix, Hermiston, Meacham, Milton-Freewater, Pendleton, Pilot Rock and Weston, and in the nearby Washington towns of Walla Walla and College Place. Staff members have also commuted from La Grande and from Plymouth, WA. The station staff are integral contributors to the communities in which they live. Volunteerism is a continuous feature of community service by past and present staff members at the Pendleton Station.

Dr. Don Wysocki administering an FFA Soil Judging Contest, in 1991

Two of the current technical staff are members of school boards in Pendleton and Pilot Rock. Previous employees have served the school boards in other communities. One scientist served for many years on the boards of the Education Service District and Habitat for Humanity. Another scientist served many years on the Pendleton City Council and, after retirement, was elected Mayor of Pendleton. One scientist serves or has served on many state, county and regional boards, and also provides expertise and service to student training, as exemplified by soil judging contests among regional chapters of the Future Farmers of America. At least three staff at the Pendleton Station have been distinguished as the ‘Citizen of the Year’ in their respective cities of residence. Numerous other staff members have served on various city or county boards and commissions.

Many of the staff and their spouses are members and have been leaders of service organizations such as Rotary International, Kiwanis International, Altrusa International, Lions International, PEO, Gideon’s International, Fraternal Order of the Elks, Young Life, and others. Staff and spouses have typically been members, participants, officers or strong contributors to national charities and particularly to local organizations such as the Oregon East Symphony, Pendleton Center for the Arts, Desert Arts Council, Friday Market, Warming Station, Salvation Army, Farm Fair, Pendleton Animal Welfare Shelter, Stewards of the Umatilla River Environment, Umatilla County Citizen’s Review Board, Umatilla County Historical Society, Pendleton Round-Up, Happy Canyon, Pendleton Underground Tours, Pendleton Progress Board, Pendleton Bike Week, Pendleton Whiskey Fest, Farmer’s Market, Toastmaster’s, and other such community and tourism functions. Numerous staff members have been leaders in their churches. Several staff members and spouses are coaches or referees for public school and Little League sports. Other staff members have had active roles in school-related arts and science education activities.

Staff members at the Pendleton Station have been involved in many group activities over the years. During the past 30 years, they have participated as groups or individuals in activities such as cleaning a section of Highway 11, serving as a volunteer crew for contestants during hot-air balloon competitions, entering floats into the Dress-Up Parades that precede the Pendleton Roundup, coordinating the participation of Oregon State University's President and Deans in the Westward Ho Parades during the Roundup, entering teams in community intramural sports leagues, teaching at Pendleton's annual Outdoor School for 6th-grade students, presentations and displays at Pendleton School District 'Career Day' events, teaching adults at the Umatilla County Master Gardener program, hosting educational tours for elementary school students, hosting tours of university graduate students from as far away as South Carolina, producing pumpkins for distribution to school children, providing learning opportunities for intellectually challenged adults, and lecturing to agriculture students at Blue Mountain Community College, Eastern Oregon University and Whitman College. This list is representative but incomplete. For at least three decades the USDA and OSU staffs and retirees also participated in Christmas parties at homes of the local OSU Superintendent and sometimes also at the home of the USDA Research Leader. Most summers, the OSU and USDA staffs and retirees participate in a group party at a community park. On one occasion, they roasted an entire pig in a fire pit at the station. Some work groups gathered annually at a local restaurant or at the lead scientist's home for a post-harvest party, before the summer crew departed. Finally, each year, the staff at the station coordinate up to six potluck luncheons to recognize new employees, honor departing employees, celebrate a holiday, or 'just because.' Social events at or by the workplace have been an important component of contributions to the community, although the level of camaraderie among staff has swelled and waned over time.

Dr. Stewart Wuest leading a discussion of plant science at Outdoor School (2012)

The value of the Pendleton Station for training students in the community cannot be overstated. The station typically employs 20 and 30 seasonal employees each year. While those employees have had highly divergent responsibilities, all have been asked to do their work accurately and efficiently. Nearly all of those employees have contributed greatly to the operations of the station's research and maintenance functions. Some employees assisted in maintaining the grounds and cleaning the facility. Others worked in the fields while collecting plant or soil samples, or harvesting grain. Others worked in a laboratory or plant-processing facility. Many were tasked with entering data into a computer; a task that cannot include any error. Workers who served the station in a competent and energetic manner were asked to return. Some did so for as many as six consecutive years. Citizens of the Pendleton community include large numbers of citizens who state "*I used to work at the Station*." Those former seasonal workers are now spread across the nation and the world, and serve in all types of occupations that include doctors, nurses, a biomedical researcher, pharmacists, university professors, teachers, farmers, homemakers, landscapers, retail merchandising, and a myriad of others. These former seasonal workers gained at least some of their incentive through challenges they met, and the good works they accomplished, while working for state or federal programs at the Pendleton Station.

Those who have served at every level of employment at the Pendleton Station have clearly become integrated into their local communities. They contributed greatly to the quality of life outside their responsibilities as employees of the USDA and the OAES.

***References*:**

Annual Reports from the Sherman and Pendleton Stations (Appendices 5 and 6)

Letters sent to or from the Station Superintendents

Maris, P. V. 1926. Report of the Wheat Growers Economic Conference, Moro, Oregon, February 11-13, 1926. Oregon Agricultural College Extension Bulletin 391. Corvallis, OR. 71 pages.

Rost, B. 1988. The Founding of the Oregon Wheat Growers League: A History. Oregon Wheat Growers League, Pendleton, Oregon. 37 pages.

Terjeson, J., and V. W. Johnson. 1947. Report of Umatilla County's Agricultural Planning Conference. January 23, 1947. Umatilla County Extension Service. 65 pages.

Zacharias, K. S. 2001. The Founding of the Oregon Wheat Growers League: A History [Commemorating the 75th Anniversary]. Oregon Wheat Growers League, Pendleton, Oregon. 37 pages.

Chapter 26 - Funding

Funding for the stations has always included a complex mixture of state and federal sources. Initially, funds from each county were also a component of the funding complex. Direct appropriations from the counties were curtailed after the stations became operational. Fund allocated directly from Federal agencies were once the major source of support for employee salaries and wages. Over time, as more personnel began to be hired directly by the OAES, direct federal funding was abolished. Since 1957, income from competitive grants, gifts and corporate sources has been increasingly and critically important for programs operated by the OAES scientists and OES extensionists. Federal scientists continued to receive direct appropriations from their parent agency. However, the state researchers and extensionists also continued to receive a portion of their support from federal programs called 'formula' funds. Those federal funds are allocated to each state based upon a formula calculated, in part, by numbers of citizens in each state. Examples of federal formula funds include the Hatch Act funds for OAES programs and Smith-Lever Act funds for OES programs. Those monies are an important but undisclosed component of 'direct' annual appropriations from the OAES and OES.

Proportions of funding from these sources evolved over time. Selected items of historical interest are discussed for two eras of the dryland stations; up to 1970, and after 1970. Sources of highly influential recent funding from external sources are also discussed.

Funding Issues (1909-1970)

The Sherman Station and the Pendleton Station were initially administered as USDA field stations. Early research was funded by a mixture of funds from USDA and OAES. For the Sherman Station, the 1909 and 1914 Memoranda of Understanding between the OAES and USDA Bureau of Plant Industry stated that the OAES would provide land, buildings, teams, machinery, supplies and ordinary labor. The USDA would furnish seed, and an "*assistant who shall be farm superintendent, and be in direct charge of all the field plat experimental work, variety tests, breeding work, etc.*" All early superintendents were required to travel to Washington, D.C. each winter to write an annual report and coordinate planning for future experiments. The detailed report of all experimental data, weather, interpretations and conclusions was required to be submitted before the last day of each year.

Other workers at each of the dryland stations were a mixture of state and federal employees who had to be jointly selected by, and acceptable to, both parties. It was also mandated that all experiments be jointly planned and conducted by the USDA and OAES. Seed in excess of that needed locally for the next sowing was required to be distributed equally to both parties, and threshed samples of all grain varieties had to be submitted with the annual report. Both parties had to share equally in the publication of research results, and in official communications. As noted in Chapter 3, there were at least three USDA units that had initial roles in developing the Sherman Station; Bureau of Plant Industry, Biophysical Laboratory and Office of Forage Investigations.

The first two administrators of the Sherman Station, Harry Umberger and David Stephens, were agronomists transferred to Moro from previous USDA positions in Washington, D.C. In 1928, Stephens also became superintendent of the Pendleton Station while continuing to reside in Moro. The assistant superintendents at each station were also USDA employees; George Mitchell, at the Pendleton Station, and Merrill Oveson, at the Sherman Station. After completion of their services at the Sherman Station, both Umberger and Stephens continued with other federal responsibilities in Washington, D.C. Neither of them remained at USDA headquarters for very long before moving elsewhere; Umberger to Kansas, and Stephens to the State of Washington.

After most Federal employees had been transferred from Moro to Pendleton, the USDA terminated its commitment to the Sherman Station in 1940. Federal funds continued for employees and research initiatives at the Pendleton Station. A decade later, the Oregon wheat industry and agri-business began to supplement funds for OAES programs. Several years after the Oregon Wheat Commission was established in 1947, that organization began allocating small amounts of funding to improve or construct buildings, or to support selected research. The first evidence of the latter, from the Commission to a scientist at a dryland experiment station, was monetary support for Bill Hall's study of the genetic inheritance of wheat milling quality. That research was apparently the first such study of that topic globally (Vogel, 1952). The first outside funding by a private corporation occurred in 1957, when Dean Swan received money from Dow Chemical

Corporation to screen herbicides. From that era to the present, agri-business and the wheat industry have been major sponsors of research at the dryland experiment stations. These outside sources have become essential for the applied research missions of the stations.

From the very beginning of programs at the dryland experiment stations, federal and state scientists have faced recurring funding deficiencies as well as delays in getting reimbursed for expenditures. These issues were especially stressing at the beginning. Umberger had to learn ways to administer the station with income and expectations from three disparate agencies; USDA, OAES, and Sherman County. Initially, the County paid for buildings, while operations and salaries were funded jointly by OAES and USDA-BPI. Each agency contributed $2,500 annually for those expenses. Issues became particularly contentious when one agency attempted to spend out of another's fund. Umberger was caught in the middle of these issues and clearly exerted his influence on resolutions. The following example is an excerpt from a 3-page letter that Umberger sent to Henry Scudder on December 13, 1910: "… *Regarding the payment of Corvallis Station salaries from our fund, I have become more determined than ever that this is not in order, and shall oppose anything of this sort for any amount. I have President Kerr's assurance of this and shall not change my attitude. I have talked with Mr. Carleton regarding the matter and he confirms my opposition to it. ... You mention our exchanging of ideas regarding the work in order that we may reach a better understanding. For my part, I shall certainly insist upon a more definite understanding regarding the expenditure of our fund. Had I been informed, as I repeatedly requested, regarding state bills, there would have been no possibility whatever of there being a deficit. ... The government fund does not revert on January 1st, and it would not be policy for me to draw upon the remaining three hundred dollars for the payment of state bills*." Umberger went on to state "… *I am also sending you an itemized statement of the expenditures of the County Fund, as well as of the Government Fund*."

Many other letters were written regarding the issue of funding sources, and especially an on-going problem caused by lengthy delays in payments of merchant accounts and reimbursements of personal expenses incurred by Umberger and his farm manager, Owen Beaty. They felt compelled to make timely payments out of their personal resources to pay the temporary laborers, and to pay the merchants who were complaining bitterly about unacceptable delays in receiving payments from Corvallis and Washington, D.C. The workers at Moro could ill afford the local merchant's threats to limit future purchases of goods and services to a cash-at-the-time-of-delivery basis.

Repeatedly, Umberger and Beaty made some of the payments out of their own pockets, and then met undue delays when they asked for reimbursement. The delay in state and federal payments and reimbursements became a point of great consternation. When Umberger travelled to USDA-BPI headquarters to write the Station's annual report during the winter of 2010-2011, he and Owen Beaty exchanged many letters regarding this issue. Topics of those letters addressed money to operate the station, payments of bills that were long overdue, and general information about the weather and the work and maintenance at the station. In a letter from Beaty to Umberger, dated February 4, 1911, there was the following statement: "*The ship still floats but there is nothing here to run it with yet. The money will be here by March 1. I paid $20 out of my pocket this morning for I have gotten tired of putting Fields off. He said he needed it and I paid him. I am going out to Buckley's Monday to prune his orchard, so will get out of sight of some of those I owe. Dr. Goffin has been paying the telephone rent since you left.*" By mid-spring, Umberger was obviously totally exasperated. On March 22, 1911, he wrote a 2-page letter to ask the College President to intervene. The letter included the following: "*Dear President Kerr: ... A statement of the revolving fund was mailed to Prof. Scudder on January 14. ... All receipts should therefore have been in the hands of your business office certainly not later than Feb. 1. I can think of no reason for the present delay in forwarding funds. There has been some misunderstanding between Prof. Scudder and myself, the correspondence concerning which has passed through your hands. Regretting extremely the necessity of calling your attention to this matter, I am, Very truly yours. H.J.C. Umberger, Superintendent*"

Umberger and Beaty quickly became frustrated by financial arrangements and processes at the Sherman Station. Within a year, both of these key employees started seeking other jobs. The agencies tried to add incentives to retain their services. In July, 1911, the USDA-BPI showed its appreciation for Umberger's ambitious leadership by adjusting his salary to the fourth-highest among the 15 field stations of the national network at that time. They also provided an increase in the operating budget, such that funding for the Sherman Station became the third-highest among the 15 field stations. They also added additional incentives to retain the services of Owen Beaty. However, in view of continual frustrations, especially regarding processing of payments, the increases in funding failed to induce Umberger and Beaty to waver from their desires to seek other employment. On August 10, Scudder, Carleton, and Kerr met to discuss the Sherman Station staff. In a 3-page letter from Scudder to Umberger, dated August 20, 1911, it was stated that they held a "*… protracted meeting … and came to an understanding whereby it will be possible to retain your services at the Moro Station*." The following winter, Umberger and Beaty each resigned and moved to other positions. David Stephens was immediately transferred from his USDA position in Washington, D.C., where he became the first long-serving administrator at the Sherman Station.

Yet, the financial challenges continued. It was clearly an issue depicted by a letter that Dave Stephens wrote to Dr. Carleton R. Ball, his supervisor in Washington, D.C. The letter dated November 16, 1926 stated "*I have your letter of the 9th, indicating the pleasure you had in writing about the cut in the Office appropriation by the Budget Committee. This information has come to us with such amazing regularity that writing about it ceases to be a pleasure with us. Apparently we have yet failed to impress the Budget Bureau with the importance of our work. … I presume there is nothing for us to do but to again appeal to Sinnot and McNary to help us out. They have done this on so many previous occasions that they may be reluctant to do it again. … Jardine is now in Washington and … he will no doubt take up the matter with Senator McNary. If Representative Sinnot is now in The Dalles, and I think he is, I shall take up the matter with him personally this week*."

The annual allocations to operate the Sherman Station remained about the same as they had been when the Sherman Station was established. Three decades after the Sherman Station was built, during the three fiscal years from 1938 to 1940, the USDA contribution remained static at $2,600 per year. However, during one year only, the USDA-BPI contributed an additional $8,000 to meet the special needs for smut research. The USDA cancelled its commitment for further direct funding of the Sherman Station during a period of austerity on July 1, 1940. In the letter of transmittal, Max McCall (Assistant Chief, USDA Bureau of Plant Industry, Washington, D.C.) stated to Merrill Oveson that "*… it is now necessary for us to discontinue our contribution to the cooperative program at Moro with the beginning of the new fiscal year on July 1st.*" "*We have appreciated the fine relationships at Moro and are very sorry indeed to see them discontinued. We are very regretful that the long and excellent service of Mr. Hoskinson has to be ended in this way. It is a matter, however, over which we have no control*."

State budgets also went through periods of difficulty that forced cutbacks in operations and staff at the Sherman Station. For instance, in the 1963 Annual Report, it was stated that the following program adjustments became necessary. "*Station operating expenses were exceeding the budget and as most reserve funds had been used in previous years it became apparent a change in the station program or an increased budget would be necessary. State legislative action did not allow budget increases. A tentative change in the station program allowing a reduction in expenses by elimination of many on-station experiments was made. Off-station fertility experiments were located in Wasco, Sherman, Gilliam and Morrow Counties. Out-lying nursery trials were seeded in Gilliam and Morrow Counties. Due to the uncertainty of the future program, Mr. Robert Bernards resigned to accept other employment. The October 15 rejection by the voters of the legislative state budget and its consequential budget cut backs has added to the seriousness of this station's financial difficulties. It is recognized that the efficiency of the station resources and personnel will be reduced until an adequate budget is provided. The 1964 program will reflect the necessary changes.*" Programs that were being eliminated included the cropping sequence experiments, the new crops experiments, and the stubble mulch and fall tillage experiment. The intensity of testing at out-lying nurseries was also reduced. Shortly thereafter, in 1964, the Sherman Station Superintendent, Bill Hall, decided that it would be a good time to take a sabbatical leave to earn a Ph.D. degree in plant breeding at Michigan State University. He left Moro and never returned. After two years, Hall's 'temporary' stand-in, Jack McDermid, became the new Station Superintendent.

Funding Issues (since 1971)

Budgets for the USDA and OAES at the Pendleton Station began to be more fully distinguished and separated upon completion of the USDA soil and water research facility at Pendleton during 1970. The number of USDA staff scientists and staff was increased significantly from 1969 through 1976. Shortly thereafter, personnel and funds associated with the OES also began to become co-mingled with funds from the OAES. Budgets of state and federal agencies at Pendleton became nearly totally separated by the early 1990s. However, there continue to be numerous transfers of funds from one agency to the other, to provide for shared services, facilities and hiring of seasonal labor. Further issues encountered by the state and federal programs at Pendleton are therefore discussed separately.

USDA Program

Funds for USDA personnel and programs were allocated at the Sherman Station from 1909 until 1940, and at the Pendleton Station from 1928 until 1970. Separation of state and federal budgets became more complete with completion of the federal construction project at Pendleton during 1970. Funding for USDA programs differed from the state programs in that administrators of federal programs were informed of their allocations in advance, and were expected to operate within that budgetary limit. The source of federal funds was therefore much more clearly defined than the mixture of funds for state programs.

Funding levels have always been somewhat less than local administrators and scientists considered adequate to perform the expectations of their positions. Allocations of funds were also subject to the vagaries of political debate and posturing. They were influenced by such factors as the harmonization of the President's proposed annual budget and the amounts agreed upon through compromises by the U.S. Senate and House of Representatives. Also, funds earmarked for specialty projects often reduced the flexibility of onward funding of USDA field units by the regional office of the USDA-ARS. Some projects were earmarked by members of Congress, and some were dictated by research prioritization by the USDA-ARS National Program Staff. Throughout all of that, the USDA unit at Pendleton has retained the flexibility to respond to those economic forces, even when those forces caused difficult decisions regarding numbers of personnel, levels of facility maintenance, purchases of replacement or new equipment, and levels and types of experimentation.

The author of this book is not conversant in the specific history of USDA budgets at Pendleton. This discussion will therefore be concluded by stating that, in 2019, the USDA program at Pendleton had an income of $1.3 million to support a staff and programs of five scientists and six technical, clerical and support staff. That funding level increase during 2020, upon passage and funding of a two-million dollar federal initiative to improve the resiliency of dryland farming programs in the low-rainfall regions, as described later.

State Program

Funding issues plagued the applied research and extension programs during the 1970s and 1980s. Previously, the primary funding for those programs came from state and federal formula funds. During the late 1970s, research by OAES scientists became increasingly reliant on competitive grants from commodity commissions, agribusiness, and federal and state agencies. These 'extramural' sources became critically important by the mid-1980s.

During the 1970s, Dr. Chuck Rohde's wheat breeding program was the only program for which a full-time technician was employed and fully paid by the OAES. A second full-time, fully-paid technician was added in 1985, when Dr. Richard Smiley initiated a new plant pathology program at Pendleton.

From 1985 until 1990, direct funding from the OAES and OES remained level but income from grants waned and costs for personnel, supplies and services became inflated. Fiscal year 1987-1988 became the first year in the station's history that salaries for scientists and other key support personnel exceeded the total amount of funds provided by the OAES and OES. In 1990, it became necessary to adjust to this circumstance by reducing operational expenditures at Pendleton and Moro by $90,000, 21 percent reduction from the base budget ($433,400). It became necessary to shift salaries and benefits for Rohde and Smiley's technicians to funds derived from outside grants, and Smiley, and to impose additional 'taxes' on extramural grants obtained by all scientists. As such, research and extension efforts became almost totally dependent on the ability of each scientist to acquire outside funds. Unfortunately, the source and purpose of the grants imposed an unduly strong influence on the focus and longevity of research projects operated by the state scientists. Nevertheless, the adjustments during that period freed up funds from the base budget to continue operating the two stations. Scientists adjusted by acquiring a higher level of funding from outside sources. From 1986 until 1992, outside grants acquired by scientists at Pendleton increased from $116,000 to $434,000 annually. But the success in overcoming the financial stress was short-lived. The proportion of total station income spent on research projects increased from 60 percent in 1986 to 85 percent in 1991, while the proportions spent on station operations and administration during 1991 declined to 10 and 4 percent, respectively.

The financial stress on the stations was exacerbated by another circumstance during November 1990. The citizens of Oregon passed Ballot Measure 5, which became one of the most contentious measures in Oregon election history. Measure 5 amended the Oregon Constitution to establish limits on property taxes on real estate, and to transfer responsibility for school funding from local governments to the state. The reduction assigned to the Pendleton and Sherman Stations was $39,000 over two fiscal years (FY 1990-91 and 1991-92), but that reduction greatly complicated the $90,000 reduction already being administered at that time. A number of other cost-cutting measures were implemented. The farm manager at Moro was laid off and a technician in the pathology program was transferred to the soil science program. The least-productive 30 percent of land farmed at the Sherman Station was converted from wheat to a perennial rangeland. Several vehicles were sold and others were removed from the vehicle replacement account, which was another tax on grant's acquired by the scientists. No temporary labor was hired for station maintenance. Another 'tax' on grants was implemented. The land-use fee charged scientists for land used by their research projects. All other general operational and maintenance expenses were reduced by 15 percent. Extension activities and business travel were also reduced.

Nevertheless, due to the scientist's excellence in acquiring grants, the late-1980s and 1990s became a time of overall growth for the Sherman and Pendleton stations. The number of technicians was increased for scientific programs, and computer systems, vehicles, farming equipment and buildings were modernized at both locations. The state full-time staffing level doubled from 1985 to 2000; from 9.5 to 20.1 personnel time equivalents. This became possible because extramural grants were quadrupled from $116,000 to $531,000 during the 15-year interval and, as importantly, critically important funds were provided by the wheat industry to support station functions.

Lobbying efforts by the Oregon Wheat Growers League led to a special federal appropriation of $160,000 to construct a new greenhouse and support facility at Pendleton during 1992. During 1997, the Oregon Wheat Commission and Oregon Wheat Foundation donated new equipment valued at $300,000 to improve research efficiency by state scientists. That funding purchased field and laboratory equipment that is still in service at the present time. Periodic special allocations from the Experiment Station were received to improve older buildings and construct additional buildings. The Sherman Station Endowment Fund also purchased equipment and improved buildings at Moro during the past three decades. The Oregon Wheat Commission funded a modernization of the plant pathology laboratory in 1999. The laboratory was equipped with instruments required to conduct research using modern molecular technologies.

In 1999, State Senator David Nelson, from Pendleton, sponsored a legislative enhancement package (Senate Bill 413) that allocated $2.4 million in additional recurring funds for wheat and small grains research at Oregon State University. The proportion directed into the Pendleton Station's budget included full funding for one additional scientist and five research assistants, one for each of the five state scientists at Pendleton. That funding removed a heavy burden from grants acquired by the scientists. This change of fortune for the stations, in 2000, provided a unique circumstance as Dr. Smiley requested permission to transfer administrative duties and a large accumulation of 'reserve' funds to the newly hired scientist, Dr. Steve Petrie.

Personnel and Income Sources for the Columbia Basin Agricultural Research Center

Personnel and Funding	1985	1990	2000	2010	2018
Administrative FTE *	0.2	0.5	0.5	0.5	0.5
Scientist FTE	3.8	4.5	4.5	4.5	3.5
Support staff FTE	5.5	12.0	15.1	12.0	7.0
Total 'permanent' staff	9.5	17.0	20.1	17.5	11.0
Institutional funds **	$375,000	$445,000	$475,000	$950,000	$1,100,000
Extramural grants	$116,000	$292,000	$531,000	$400,000	$305,000
'Block grant' ***	-	-	-	-	$175,000
Total income	$491,000	$737,000	$1,006,000	$1,350,000	$1,580,000

* FTE = full-time equivalents for 'permanent' appointments; excludes temporary labor & post-doctoral scientists

** Funds directly allocated by the OAES and the OES, including income from sales of grain harvested at the stations

*** This temporary grant from the Oregon Wheat Commission was first allocated in 2011 as basic support and maintenance of the stations; research-specific grants from the OWC were included as income from extramural grants

The funding stability attained in 2000 was short lived. In 2002, the Experiment Station and Extension service administered a reduction of funds for all branch experiment stations. This was addressed at the dryland experiment stations by forcing OAES scientists to contribute funds equal to 25 percent of the salary and benefits for the five research assistants who had just become fully funded by legislative action during 2000. An equivalent amount was therefore freed up in the Pendleton Station's budget, so to allocated to costs for general operations. Once again, this renewed the pressure on scientists to acquire additional funds for their research and extension activities. Part of the newly sequestered money was used in 2004 to enter upon a long-term lease for 35 acres of additional land immediately north of the Pendleton Station. An additional lease for another 17 acres was added during 2014. One year later, the land owner notified the Station of his intent to sell both of the leased fields. The Station had no money with which to buy the fields. Therefore, the Oregon Wheat Foundation purchased the leased land (about 60 acres) and immediately leased it back to the Pendleton Station. The fee for those leases has imposed a burden on the Pendleton Station's budget, although the land has proven to be a useful and sometimes essential resource for experiments.

Extramural income has been variable over time, as would be expected for applied research initiatives, which are funded heavily by grants and contracts based upon 1-year cycles of proposals and annual reports. However, the running 3-year average total for extramural grants was particularly good during the mid-2000s. The average annual income for grants during 3-year intervals ending in 2005, 2006, 2007 and 2008 were $640,000, $576,000, $562,000, and $610,000, respectively. The single year incomes during 2007 and 2008 were $587,000 and $643,000.

During 2011, the OAES issued a directive for each branch station to acquire a commitment from a local resource to provide 25 percent of its operational expense into perpetuity. The Oregon Wheat Commission reluctantly agreed to provide a special but temporary 'block grant' of $250,000 to support operations of the Pendleton and Sherman stations. After several years the funding level began to decline and some Commissioners indicated they were inclined to terminate that 'temporary' allocation. In 2017, the amount provided to the stations was $175,000. An alternative source of funding was explored during 2018. The OSU Extension Service requested establishment of a special tax district in which citizens of Umatilla and Morrow counties would provide funds for extension staff and activities, plus $250,000 annually to support operations of the Pendleton and Sherman Stations. Measure 30-126 proposed a tax rate of 33 cents per $1,000 of assessed property value. The voters defeated that measure.

The OAES further disinvested in its dryland research stations during 2014. As scientists retired from 12-month appointments at Pendleton they began to be replaced by scientists hired on 9-month appointments, without a paid vacation, in the manner routinely applied to 9-month teaching positions at the university and at local schools. In view of all-year requirements for applied agricultural research and extension by branch station scientists, these scientists were discouraged from taking outside jobs during the three months in which they would not be paid by Oregon State University. Moreover, the newly-hired scientists were encouraged to acquire additional extramural funds to fulfill the shortfall in their salary and benefits, and to provide themselves a paid vacation. This ill-conceived and self-damaging practice continues at the present time, and even included one of the most recent CBARC administrators. During 2015, at a time of administrative strife at CBARC, the OAES transferred that Director to Corvallis and replaced the position with an even lower-level appointment. A half-time extensionist was hired to administer CBARC while, at the same time, retaining a primary office and unrelated extension administration duties at another location. That transition further diminished the capacity of the Station to acquire extramural grants. It is refreshing that a new OAES administration is preparing at the current time to once again employ a full-time administrator who will also be responsible for research and extension.

The following table summarizes several key personnel and economic statistics for the OAES and Extension Service programs at Pendleton and Moro during the past three decades. Funding was rounded to the nearest thousand dollars.

Extramural Funds

The term 'extramural' refers to funds that are acquired by individual scientists in response to proposals they submitted for a specific research or extension objective. While this funding has been much more critical for state than federal scientists, these targeted sources of outside funding are by no means limited to state scientists. Extramural funds are received as either a contract that requires dedicated research and reporting, or a gift that is less restrictive with respect to spending and reporting. Income as a contract is nearly always based upon allocations made from organizations who have invited scientists to compete for funds from a limited pool of money. An overview is provided for sources of extramural funds acquired by scientists at Pendleton. Each of these sources have been important for experimental services provided by the stations.

There have been numerous grants acquired from regional or national programs. Some of those sources were programs for Cool-Season Food Legume Research, Low-Input Sustainable Agriculture, Integrated Pest Management, Dwarf Bunt (TCK Smut), Canola Research, Russian Wheat Aphid Research, Dinoseb Replacement, Jointed Goatgrass Control, Impacts of the Conservation Reserve Program, Wind Erosion and Air Quality Control, and Kentucky Bluegrass Seed Production. Other federal funds were received from the Tennessee Valley Authority and the USDA-SCS. Special grants were also received from state agencies, including Oregon Department of Agriculture, Washington Department of Ecology, and OSU Agricultural Research Foundation. Private funding was received from the Rockefeller Foundation, National Association of Wheat Growers, Boise Cascade, and many dozens of manufacturers of pesticides and fertilizers. A mixture of these sources was considered normal and to present the lease risk of programmatic collapse, should any one source become terminated.

Five specific sources of were particularly well sustained and important sources for funding; Oregon Wheat Commission, Sherman Station Endowment Fund, USDA Specific Cooperative Agreement '*Root Diseases of Wheat and Barley*', USDA-STEEP program (*Solutions to Economic and Environmental Problems in the Pacific Northwest*), USDA-REACCH program (*Regional Approaches to Climate Change for Pacific Northwest Agriculture*), and USDA Resilient Dryland Farming Initiative. These six sources will be discussed in greater depth.

In 1994, extramural funds acquired by OAES scientists at Pendleton were distributed as follows: 26 percent from Oregon Wheat Commission, 38 percent from the STEEP program, 15 percent from other USDA agencies, 10 percent from State agencies, and 11 percent from corporations.

Oregon Wheat Commission

The Oregon Wheat Commission was established during 1947 as a means for collecting a tax on wheat production and allocating the receipts in a manner that benefited the wheat industry in Oregon. Hill and Jackman (1960) and Weatherford (1969) provided historical perspectives of events that led to the Commission's establishment. An account is also available at http://www.owgl.org/consumers/history/how-the-owc-was-formed/. Briefly, the Oregon Wheat Growers League established a committee in 1945 to examine ways that growers could "*…find an equitable way of providing a reasonable amount of money on a continuing basis for working on their own problems*." E. R. Jackman, Extension Crop Specialist at Oregon State College, sent a letter to the committee chair, Jens Terjeson, to suggest that a new organization be established and structured similar to the potato commissions in Idaho and Maine. The concept was studied, gained favor, and was formalized during the League's annual meeting on December 18, 1946. The League recommended a legislative act to form the Commission as a State agency, and it be given authority to collect a tax of one-half cent per bushel of wheat grown in the state and sold through commercial channels. Terjeson and Marion Weatherford were the two most important and persistent League members that traveled to Salem to lobby for passage of House Bill No. 176 by the State Legislature. The founding legislation was passed in 1946 and the Commission was formed on February 28, 1947. The Commission was composed of five wheat producers, three of whom resided in the Columbia Basin counties. Ex-officio members were representatives of the State Department of Agriculture and the Oregon State College. The first meeting of the Commission occurred on April 27, 1947. Its' purpose is to "*promote the production, marketing and utilization of Oregon wheat to the end that producers maintain a permanent agricultural production and that the crop be utilized to the fullest development of the area*." Many more commissions for other commodities in Oregon and nationally have been founded more recently.

The Commission's earliest direct support for wheat research was the allocation of funds to study wheat quality issues at laboratories in Peoria, IL, Albany, CA, and Pullman, WA. The Commission was then instrumental in assisting the Pacific Northwest wheat industry to acquire federal funds for studies of common bunt at Pullman, WA and Corvallis, OR. Much of that research was conducted at the Sherman Station and Pendleton Station (see Chapter 20). In the next large initiative, in 1948, the Commission assisted the Eastern Oregon Wheat League to secure federal funding for establishing large-scale research in Umatilla County for the control of erosion and to achieve sustainable yields. That funding became the basis for off-station research at the King, Hill and Crow 'Pilot' Farms (see Chapter 5).

During a 1953 report of Commission activities during at the annual meeting of the Oregon Wheat Growers League, Paulen Kaseberg (1953) stated "*In addition to some of these continuing projects the*

Commission has found it necessary to make certain capital expenditures at both Pendleton and Corvallis in order to get some research projects started. These have not been made except after exhausting all other sources because the Commission feels that the tools of research are more properly the responsibility of the people of the State of Oregon and of the Federal Government. Therefore, whenever an essential job was going to be left undone we have stepped in and furnished the tools necessary to do that job and see that it was done at the time it must be accomplished." Kaseberg then specifically mentioned research on smut and on soil erosion, but no further detail was presented. He then continued "*I might say here and now that unless more adequate financing is forthcoming there is a real danger that the work of the Moro Branch Experiment Station will be curtailed*." It was during the previous decade that the level of staffing had shifted from Moro to Pendleton. Oveson and Besse (1967) stated that "*in recent years the Oregon Wheat Commission has assisted in providing funds for enlargements and improvements of buildings*" at the Pendleton Station. In 1969 the Commission directed $500 for "*Emergency – Field Sanitation Burning Research*."

The Commission became an essential and routine component of agricultural research at the Pendleton and Sherman Stations during 1976 (Tubbs, 1975). The assessment from wheat producers was doubled during 1975, from 0.5 to 1.0 cents per bushel. This increased industry support for OAES statewide research from $25,000 to $72,500. During 1976 the Commission established an 'annual specific performance contract basis' to oversee the distribution of funds for worthy research projects at the Corvallis, Pendleton and Moro stations, and for annual renewals of those allocations upon approval of the Commission. The process involved an annual written proposal from scientists, and oral and written progress reports. From that time to the present, the Commission's sponsorship of wheat-related research has provided valuable and essential funding for scientists who conduct research at the dryland experiment stations. The monetary amount has varied from year-to-year in accordance with scientists research objectives and the Commission's priorities. As an example of the importance of these funds, in 1994 the Commission allocated $93,000 to four OAES scientists stationed at CBARC, which equated to 26 percent of total extramural funding for those scientists. That same year, the total of extramural funding represented 40 percent of total income for the research center.

Sherman Station Endowment

The Sherman Station Endowment was established in 1992 to develop funds "*directed toward supporting the agricultural research needs of the Sherman Station, located in Moro, Oregon. The support may include, but not be limited to: facility improvement, research programs, personnel and other integral needs to best achieve the research needs and goals*." The endowment was organized largely through the vision and organizational efforts of Ernest Moore and Steve Anderson, who were leaders of the Sherman Station Liaison Committee. Support for that initiative was provided by Richard Smiley, CBARC Superintendent, and Betty Brose, Manager of Development for the Oregon State University Foundation. The Endowment funds are administered by the chair and three regular members of the Sherman Station Liaison Committee, the Sherman County Judge, the Station Superintendent, and the Director of the OAES. The Endowment began to contribute farm and laboratory equipment, labor, and facilities enhancements within five years after establishment. It was the first Endowment established in Oregon to support an off-campus research station, and it remains the most successful of current endowments. By 2018, the Sherman Station Endowment attained a value of approximately one million dollars. Interestingly, the Sherman Station was the template used to establish the Dryland Agricultural Experiment Station at Lind, WA in 1915, and the Sherman Station Endowment became the template for establishing an endowment to support research at that station in Washington.

USDA Specific Cooperative Agreement for Root Research

Congress passed legislation in 1997 authorizing $500,000 to enhance wheat and barley root disease research in the Pacific Northwest. That action was in response to wheat and barley industry support for a targeted research initiative proposed by plant pathologists Drs. R. James Cook (Washington), Richard Smiley (Oregon), and Robert Forster (Idaho). The USDA-ARS Root Disease and Biological Control Research Unit, at Pullman, WA, was the only federal laboratory that specialized in root diseases of wheat and barley. Collaborations between ARS scientists and plant pathologists at regional universities had been previously impeded by a lack of on-going funds for collaborative and complementary research. Cook and Smiley prepared a concept paper calling for development of stronger linkages between federal and state research programs. Wheat and barley organizations in the three Pacific Northwest states expressed support and lobbied members of Congress. The National Barley Improvement Committee and the Washington Association of Wheat Growers provided primary leadership. Key sponsors of the 1997 legislation were Representative George Nethercutt and Senator Slade Gorton, both of whom were from Washington. Funding was not allocated during 1997 but was reauthorized in 1998, and has been funded from fiscal year 1999 to the present. Congress doubled the initial funding level for the second and subsequent fiscal years, bringing the total to $1 million annually starting in fiscal year 2000. While the level of funding slowly declined over years, this initiative became a pivotal milestone for sustained and collaborative root disease research in the Pacific Northwest.

Funds were distributed through the USDA-ARS Pacific West Area Office according to a formula stated in the authorizing legislation and published in the Federal Register; 60 percent divided between ARS (at Pullman) and Washington State University, 25 percent to Oregon State University at Pendleton, and 15 percent to University of Idaho. Funds were transferred to the universities through contracts called Specific Cooperative Agreements. The OSU contract was for $202,475 during FY2001 and declined to $56,000 during FY2012 but was adjusted and stabilized at $85,000 during FY 2013 and thereafter.

USDA STEEP Program

A Pacific Northwest regional program funded by the USDA had especially strong influence on research and extension activities at the dryland experiment stations. The STEEP (*Solutions to Economic and Environmental Problems in the Pacific Northwest*) project became established after farmers and the grain industries in Idaho, Oregon and Washington expressed concern over the long-term decline in productivity of winter wheat, particularly where soil erosion was prevalent. The agricultural experiment stations in each state engaged these farmers in discussions with the goal of determining how to mitigate problems associated with soil erosion by water and wind. Research projects involving scientists, farmers and the grains commissions in each state were prepared during the early-1970s. A review of those proposals made it clear that a regional approach would be more efficient than single-state research initiatives. The primary motivators and financial and political sponsors for the regional approach were the wheat commissions and the associations of wheat growers from each state. Representatives of these groups met in 1974 to formulate a proposal for Federal funding. Participants also included representatives from the three agricultural experiment stations and the USDA-ARS units at Pullman, WA and Pendleton, OR. Federal legislation was passed in 1975 to form a tri-state regional soil erosion control project; STEEP (Michalson, 1999; Papendick and Michalson, 1999).

Two regional committees were established to organize and direct the project. A Coordinating Committee managed research and extension grants using a process of competitive proposals. The coordinating committee included representatives of all the above-named entities plus the USDA-SCS, now known as the Natural Resource Conservation Service (USDA-NRCS). This committee examined all new proposals and minimized or eliminated duplication of efforts within and between the three states. A Grower Advisory Committee was established to assure that farmers had direct input and voting power regarding research proposals being solicited and/or considered by the Coordinating Committee. The growers also had a key role in suggesting research that would be important to them as they adopted new conservation practices.

The STEEP program was funded annually from 1976 through 2010. About $1 million annually supported proposals by university scientists, and an equal amount was directed into USDA-Agricultural Research Service budgets in the Pacific Northwest. Approximately 70 participating state and federal scientists were able to sustain multi-year team-type applied research projects that were far more efficient and productive than can be achieved through smaller, single-year projects that are able to be formally authorized by the wheat commissions. Improved farming practices were integrated into complete farm management systems that minimized erosion without adversely affecting the costs and levels of production (Kok, 2007; Kok et al., 2009). An important proportion of STEEP research in Oregon was performed at the two dryland stations. As an example of the importance of these funds, in 1994 the STEEP program allocated $139,000 to four CBARC scientists. That allocation represented 38 percent of total extramural funding for those scientists, and the extramural fund category represented 40 percent of the total income at the research center during that fiscal year.

Results of research in the STEEP program became especially pertinent and important upon passage of the 1985 Food and Agriculture Act (the ‘farm bill’), which required farmers to develop and adhere to a conservation plan in order to become eligible for government payments and other benefits, such as crop insurance. Another of the landmark accomplishments of the STEEP program was the initiation of what has become a thriving organization that continues to organize well-attended annual meetings; the Pacific Northwest Direct-Seed Association (Cook, 2001).

USDA REACCH Program

The STEEP program was succeeded by another regional coalition of Pacific Northwest scientists, who were funded by USDA to examine implications and resiliency of agriculture in response to changes in climate (Eigenbrode, 2015). The REACCH (*Regional Approaches to Climate Change for Pacific Northwest Agriculture*) program also operated through a Scientific Advisory Panel and a Stakeholder Advisory Committee. A legislative act established and funded the REACCH program for a period of five years, from 2011 to 2016, with a budget of $20 million. Funds were allocated directly (non-competitively) to approximately 30 pre-identified scientists or groups of scientists at four institutions in the three states. Each project was invited to conduct research and extension efforts that would lead to improved carbon sequestration, nitrogen-use efficiency, and resilience to a changing climate, including development of models that could predict effects of climate changes on pests and crops. One of the REACCH projects was coordinated by an Oregon State University scientist at the Pendleton Station. The REACCH program provided significant funding for operations of the long-term experiments at the Pendleton and Sherman Stations. Results of research conducted with funds from the REACCH program were published by Yorgey and Kruger (2017).

USDA Resilient Dryland Farming Initiative

The most recent allocation of funds for programs at the dryland research stations was a special federal appropriation of $2 million annually over a five-year period, from 2019 through 2024. This grower-envisioned and grower-led allocation was unique in that it was targeted specifically to the USDA unit at the Pendleton Station. The appropriation encouraged, through long-term funding and accountability, a closer collaboration among federal and state scientists at the station. The goal was to develop improved dryland production practices to increase farm profitability in areas of low rainfall. Thirteen scientists from a wide range of disciplines were assembled to conduct the research. Their specific goals are to find a way to increase the amount and quality of wheat produced, to improve soil conservation, storage of water in soil, and soil health. Research methods include the development of more intensive and diverse cropping systems that are likely to be more resilient to drought, heat and diseases. These cropping systems should also enable farmers to reduce their reliance on herbicides to manage weeds. The newly developed farming practices will be evaluated for economic and environmental benefits and sustainability. This initiative was appropriated in response to lobbying efforts by members of the Oregon Wheat Growers League and the Pendleton Station Liaison Committee. Funds were provided to hire three new USDA scientists (crop physiologist, agricultural economist, and bio-information specialist) capable of examining complex microbial and genetic data that may reveal how management practices affect soil health. First-year funds became available in 2019 to improve research facilities, purchase relevant equipment, and hire additional technical assistance. One quarter of the funding was sub-contracted to OSU scientists, who entered upon research collaborations with the USDA scientists. Field research began during 2019 on two leased commercial fields (in Morrow and Umatilla counties) and on the Sherman and Pendleton Stations. Initial alternative crops being tested include Austrian winter pea, winter lentil, and spring plantings of mustard, barley, teff and safflower. Initial cover crops being tested include pea, clover, mustard, radish, barley, vetch, and mixtures of these crops.

Justification for the Station's Existence

Each of the dryland experiment stations have faced periodic challenges from some who questioned the value of continued expenditures. While there have been no serious threats to close the state portion of the Pendleton Station, federal programs at Pendleton have been subjected to periodic challenges. Too often, there has been a need for the Oregon wheat industry, Oregon State University, and soil and water conservation districts to vigorously oppose proposals to move federal operations from Pendleton to an out-of-state location. This typically occurs when the federal facility at Pendleton is marked for closure in initial budgets proposed by a U.S. President. Lobbying then becomes necessary to convince legislators that the work of the station is critically important and deserves funding for continuation.

The Sherman Station has also faced sometimes serious threats of closure. Challenges began early and have continued into recent decades. Two examples are used to exemplify this issue. On February 8, 1920, Dave Stephens sent a 5-page single-spaced typewritten letter to President W. J. Kerr "*I have just received a letter from Mr. Jensen, asking me to send you at once a "brief, concise, but definite statement of a few of the outstanding accomplishments" of the branch station, with an approximation of the value of these accomplishments to the State in dollars and cents.*"…"*We think our insignificant, little appropriation from the State of $2,500 a year will be returned a thousand-fold annually to its citizens from the work we have already done during the eight years of our existence. We also believe that we can continue to be of great service to the State, because most of the real, fundamental problems pertaining to agriculture of this great Eastern Oregon county have not yet been solved. Our most serious and difficult work is still ahead of us*." The next four pages detailed specific achievements and estimates of the dollar returns annually for each achievement. It described attributes of new and better grain varieties ($2,116,000), better tillage methods ($3,000,000) and rotations ($300,000), for a total of "*a little more than a thousand times the annual State appropriation to the Branch Station.*"

Two years later, on March 21, 1922, Stephens contributed much of the input for a 20-page report on the importance of branch stations and the home station, attributed to and signed by James T. Jardine, Director, OAES. "*… Agricultural history does not indicate that there would have been material change in methods or improvement in crops from 1909 to 1921 had it not been for the Agricultural Experiment Stations*."

"*<u>The Sherman County Branch Station</u>: This station was established in 1909 to investigate and experiment concerning problems of dry land agriculture. At that time crop failures and low yields were not uncommon in the Columbia Basin. Today they are hardly known in the same sense. The station has been a prime factor in an increase of at least 25 percent in the acre yield of wheat between its establishment in 1909 and 1920, … for about 500,000 acres in the Columbia Basin of Oregon, to which the station results apply*."

"*<u>Value of increase</u>: This increase annually amounts to more than 1 ½ million bushels with little or no increase in labor for production. At $1.00 per bushel it means over $1,500,000. The increase has been due largely to (1) The introduction of improved strains of Turkey wheat, which yields three bushels per acre more than wheats previously grown, (2) By working out, proving, and demonstrating the value of early plowing of summer fallow, (3) By other improvements in farming practice which are actually being put into application*."

"*<u>Cost of these results</u>: These results worth a million and a half to Oregon annually have been accomplished at a total cost of $36,000 by state appropriations and about $40,000 of Federal appropriations; and the use of land and buildings which have more than doubled in value.*"

"*<u>Future Prospects</u>: (1) This station has released a new spring wheat which out-yields the commonly grown spring wheats by 4 to 5 bushels and is superior in milling quality. (2) This station in cooperation with the Home Station and the Federal Government has discovered new varieties of wheat totally resistant to stinking smut. This fact materialized will mean more annually to Oregon than the cost of all Oregon Stations for <u>five years</u>*."

It was stated earlier that a potential to close the Sherman Station was an item for specific mention in the 1953 Annual Report of the Oregon Wheat Commission. Additional challenges were faced during the 1990s, particularly after Oregon Ballot Measure 5 was passed. All units receiving state funds were required to identify measures they would implement to reduce spending by 5, 10 or 25 percent. The Superintendent, Dr. Smiley, was asked to consider closing the Sherman Station which, at that time, was the home base for only two full-time employees. Dr. Smiley successfully demonstrated that savings likely to be accrued by closing the station would impose a cost:benefit ratio far too great to be of value to the state.

Other Funding-Related Issues

During the early years, all government property was required to be inventoried annually. This micro-oversight, to the extreme, was very costly in terms of time and also to the psyche of scientists. For instance, when property was inventoried it literally meant counting everything, including pencils, pens, bolts, nuts, washers, nails, staplers, horses, plows, harrows, and all others. That took immense amounts of time each year. Similarly, items shown on previous inventories but no longer in use had to be requested to be taken off the inventory by submitting signed copies of the "*Request for Release of Property Worn Out, Lost, Stolen, Obsolete, For Sale, or Exchange.*" These forms had to go through five layers of authorizing signatures at OSU, including the Business Manager, Property Custodian, and 3-member "Board of Survey." As an example, the following entry was dated December 18, 1947. It requested permission to dispose of the following: "*1 Kitchen Range (Majestic), 1 Electric Range (Hot Point), 1 Water Heater (electric), 1 Refrigerator with Kelvinator compressor, 1 Evaporator F5K with expansion valve, and 1 Oil burner with storage tank*". Inventory numbers were shown for each entry. The stated reason for removal from inventory was "*Destroyed by fire August 28, 1947.*" The authorities were already knew that the Superintendent's residence had burned to the ground. Another interesting entry, dated September 19, 1940, was shown as follows: "*1 Bay horse, 26 yrs old, "Doc", 2000 lbs*." The stated reason for the request to take this item off the Station's inventory was "*Horse died*", and the Station Superintendent then signed a sworn statement that this state property was "*of no further service*."

The State of Oregon was not alone in implementing that type of micro-management. The Executive Assistant for Cereal Investigations, in Washington, D.C., wrote a 1-page memo to David Stephens on October 30, 1922. The memo included the following: "*Dear Mr. Stephens: You will please find enclosed two copies of "Report of Property Lost or Damaged" each of which should be signed by you at the point marked X. … Please return these two forms to this office signed as requested and furnish in a separate letter to be attached to the forms information as to when the pen was lost and under what circumstances and any other details which will enable the Bureau of Board of Survey to come to a just decision regarding the responsibility*." Stephens replied by letter on November 7. The entirety of his response was as follows: "*I have your letter of October 30th relative to the loss of a fountain pen which was Government property*. *I think the original cost of this pen was something like $1.50 and in view of this, I suggest that you carry it on the inventory and at some future date when I leave the service, I shall return a fountain pen to the office to replace the lost one.*"

The level of detail described in these passages was not limited to accounting measures alone. Exasperating expectations have been demanded of Station Superintendents by higher administrators throughout the life of the dryland stations. One early example was the following, sent to Umberger by Mark Carleton, Acting Cerealist-in-Charge, Grain Investigations, USDA Bureau of Plant Industry in Washington, D.C. A 1-page letter, dated June 13, 1910, included the following: "*I am writing to you in regard to the work at the Moro Station. I desire to obtain a weekly report during the summer from each of the dry-land grain stations, giving the crop, weather, or other conditions in any way affecting the experimental work of the stations. The reports should be prepared and sent in on Monday of each week.*"

References:

Annual Reports from the Sherman and Pendleton Stations (Appendices 5 and 6)

Letters sent to or from the Station Superintendents

Cook, R. J. (editor). 2001. Retooling Agriculture: A report on direct-seed cropping systems research in the Pacific Northwest. Pacific Northwest Extension Bulletin 553. Washington State University.

Eigenbrode, S. 2015. REACCH and the REACCH legacy. Pages 4-5. In: REACCH Annual Report: Year 4. University of Idaho, Moscow, Idaho. 139 pages.

Hill, D. D., and E. R. Jackman. 1960. *They Broke the Trail*. Oregon Wheat Commission, Pendleton, Oregon. (revised Nov. 1965). 20 pages.

Kaseberg, P. 1953. Report on activities of the Oregon Wheat Commission. Pages 75-79. In: Proceedings of the 26th Annual Meeting of the Oregon Wheat Growers League. La Grande, Oregon. December 3-5, 1953. 136 pages.

Kok, H. 2007. STEEP Impact Assessment. Report of a USDA Special Research Grant. Washington State University; on-line at http://cru.cahe.wsu.edu/CEPublications/EB2035Ea/EB2035Ea.pdf

Kok, H., R. I. Papendick and K. E. Saxton. 2009. STEEP: Impact of long-term conservation farming research and education in Pacific Northwest wheatlands. Journal of Soil and Water Conservation 64:253-264.

Michalson, E. L. 1999. A history of conservation research in the Pacific Northwest. Pages 1-10. In: *Conservation Farming in the United States: The Methods and Accomplishments of the STEEP Program* (E. L. Michalson, R. I. Papendick, and J. E. Carlson, editors). CRC Press, Boca Raton, Florida. 233 pages.

Oveson, M. M., and R. S. Besse. 1967. The Pendleton Experiment Station: Its development, program and accomplishments … 1928 to 1966. Oregon Agricultural Experiment Station Special Report 233. Corvallis, OR. 20 pp.

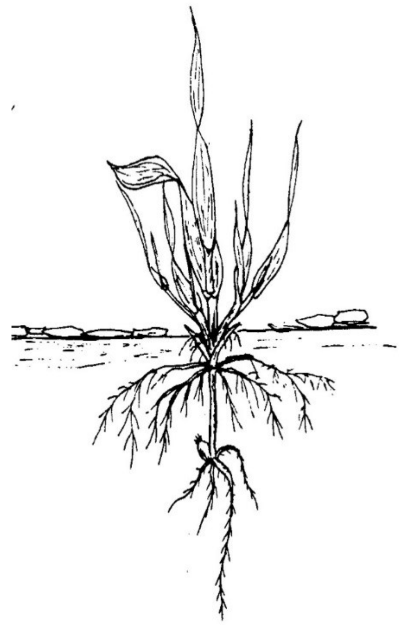
Papendick, R. I., and E. L. Michalson. 1999. STEEP -- A model for solving regional conservation and environmental problems. Pages 23-22. In: *Conservation Farming in the United States: The Methods and Accomplishments of the STEEP Program* (E. L. Michalson, R. I. Papendick, and J. E. Carlson, editors). CRC Press, Boca Raton, Florida. 233 pages.

Tubbs, F. 1976. Report on activities of the Oregon Wheat Commission. Pages 94-98. In: Proceedings of the 49th Annual Convention of the Oregon Wheat Growers League. Portland, OR. December 6, 7 and 8, 1976. 110 pages.

Vogel, O. A. 1952. The cooperative wheat improvement program in the Pacific Northwest. Pages 69-79. In. Proceedings of the Silver Anniversary Meeting of the Oregon Wheat Growers League. Portland, Oregon. December 4-6, 1952. 140 pages.

Weatherford, M. T. 1969. *The Informal Story of How the Oregon Wheat Commission was Formed*. Oregon Wheat Commission, Pendleton, Oregon. 16 pages.

Yorgey, G., and C. Kruger. 2017. Advances in Dryland Farming in the Inland Pacific Northwest. Washington State University Extension Publication EM108. Pullman, Washington. 614 pages.



Chapter 27 - Liaison Committees

Administrators of the CBARC and the CPCRC established two industry liaison committees during 1985. This was done in collaboration with farmers and agribusiness representatives throughout the region. One committee focuses upon the lowest rainfall region served most directly by the Sherman Station. The other committee addresses a greater diversity of regions served by scientists located at Pendleton. Farmers and agribusiness representatives who serve on these committees provide guidance and support for the efficient operation of the centers.

Members of the committees are appointed by the Director of the OAES, with communication and concurrence with the Director of the Pacific West Region of the USDA-ARS. As such, the committees may report directly to the higher administrations of those agencies.

The liaison committees typically meet for regular meetings as often as twice annually. They gather for special meetings as needed. The meetings include discussions of topics of importance to individual stations of the research centers, such as funding, research needs, station maintenance and appearance, selection of new faculty members, or other topics. The committees have been of particular importance during periods of financial stress, and at times when the CBARC Director or CPCRC Research Leader has a need to garner local input and understanding before administering difficult and potentially contentious actions such as staff reductions or major changes to the physical structure of a station or center. The committees also provided the impetus for development of endowment funds to provide supplemental money for physical improvements and equipment at the two locations. Members of the committees are often called upon to serve on search committees during transitions of scientists and administrators.

The Sherman Station Liaison Committee consists of 10-persons who "*Represent the agricultural interests of northcentral Oregon and southcentral Washington and serve as liaison to the Columbia Basin Agricultural Research Center, with particular reference to research programs and facilities, priorities, and resources, and generally the ways in which the Center can better serve agriculture in these areas*." Members of the committee at Moro represent the research interests of farmers in Morrow, Gilliam, Sherman and Wasco counties in Oregon and Klickitat County in Washington. Ex-officio members include the Director of CBARC, chair of the Pendleton Research Center Liaison Committee, the Sherman County Judge, and an extension service representative from each of the counties served by the committee.

The Pendleton Research Center Liaison Committee has traditionally included 16 persons who "*Represent the agricultural interests of northeast Oregon and southeast Washington and serve as liaison to the USDA Agricultural Research Service and OSU Columbia Basin Agricultural Research Center, with particular reference to research programs and facilities, priorities, and resources, and generally the ways in which the Center can better serve agriculture in these areas*." Members of the committee at Pendleton represent the research interests of farmers in Wasco, Sherman, Gilliam, Morrow, Umatilla, Union, Baker and Wallowa counties in Oregon, and in Garfield, Walla Walla, Columbia, Benton, and Franklin counties in Washington. Representatives of the Oregon Wheat Commission and the Oregon Wheat Growers League also serve as full members of the committee. Ex-officio members include the administrators of CBARC and CPCRC, chair of the Sherman Station Liaison Committee, and representatives from the extension services in Umatilla, Union, Morrow, and Walla Walla counties, the OAES, and the Umatilla County office of the USDA-NRCS.

Chapter 28 - Contributions to Agriculture and Society

(*as abbreviated, using key words*)

Erosion control
- tillage systems
- crop residue management
- economics of conservation tillage
- equipment development
- variety × management interactions

Pathogen ecology and disease control
- pathogen biology
- cultural management
- chemical control
- genetic resistance
- biological control

Soil chemistry and fertilizer efficiency
- nitrogen
- phosphorus
- sulfur
- micronutrients

Weed ecology and control
- weed biology
- cultural management
- chemical control

Attempts to develop alternate crops
- pea, corn, alfalfa, safflower, lupin, lentil, rape, others
- yield potential and quality
- variety × management interactions

Plant breeding
- wheat, barley, and triticale
- yield and quality improvement
- insect and disease resistance
- winter hardiness
- variety × management interactions

Integrated production management
- whole cropping systems
- water use efficiency
- mathematical modelling of crop growth and yield

Others
- regional weather stations
- grasses for soil stabilization
- diversion channels
- erosion control dams
- contour farming
- wind breaks
- tree, shrub and flower adaptation
- annual field days
- only low-rainfall, non-irrigated field crops research stations in Oregon

Leadership & volunteerism
- communities
- region
- state
- national
- international

Chapter 29 - The Research Centers in 2020

The state and federal programs at Moro and Pendleton continue to serve current interests and future needs of dryland agricultural industries in the Pacific Northwest. They also continue to contribute to science nationally and internationally. Both centers are vibrant and gaining or regaining strength through 1) additions of new administrative, scientific and technical staff, 2) remodeling of research facilities, and 3) pursuing new research objectives and funding. This is an overview of personnel and infrastructures of the dryland research centers in early 2020.

Scientists and Administrators

The CBARC staff consists of four scientists and a half-time administrator. The scientists include Drs. Steven Machado (Agronomist), Christina Hagerty (Plant Pathologist), Judit Barroso (Weed Scientist) and Ryan Graebner (Statewide Testing of Cereal Crops). Ms. Mary Corp (Director) communicated her intent to retire in June 2020. The OAES is currently searching for a research scientist to serve as Director. Dr. Donald Wysocki (Soil Scientist) continues his research and extension activities at the research centers and throughout eastern Oregon, but is now located at the Umatilla County Extension Service office. Dr. Richard Smiley (Plant Pathologist and former Director) is a retiree who continues as a volunteer.

The USDA staff consists of four scientists, one of whom also serves as interim Research Leader. The scientists include Drs. Stewart Wuest (Soil Scientist and interim Research Leader), Hero Gollany (Soil Scientist), John Williams (Hydrologist), and Catherine Reardon (Soil Microbiologist). Dr. Daniel Long (Agronomist and former Research Leader) recently retired and is continuing as a volunteer. The USDA will refill Dr. Long's position of Research Leader, and has new funding to add two additional scientists (Crop Physiologist, and Agricultural Economist) and one support scientist (Computational Biologist; aka 'Bioinformationist').

The centers also host an ever-changing number of visiting scientists, some of whom were on sabbatical study leave from other institutions, and others who were doctoral candidates or post-doctoral scientists. Each research center is presently hosting one visiting scientist. CBARC is actively seeking another post-doctoral scientist.

Technical and Office Staff

The number of technical staff evolves over time, depending mostly upon funding, resignations and retirements. Some appointments are for a short term, based on availability of funds or on limits imposed by an agency's policy. Finally, some transitions are unexpected and premature, as a response to changes in local administration.

CBARC support staff currently includes seven technical staff (Kyle Bender, Jennifer Gourlie, Kyle Harrison, Matthew Hunt, Duncan Kroese, Larry Pritchett, and Daisy Rudometkin) and two office staff; Debbie Sutor and Susan Philips. Bender and Harrison serve as managers of buildings, grounds, equipment, vehicles, and field programs at Moro and Pendleton, respectively. An eighth technical staff member (Alan Wernsing) is located at CBARC to support Dr. Wysocki's program.

USDA support staff currently includes three technical staff (Wayne Polumsky, David Robertson and Steve Umbarger) and three office staff (Jennifer Olsen, Tracy Olsen and Jean Wise). Umbarger serves as manager of buildings, grounds, equipment, vehicles, and field facilities and programs.

During recent years, USDA regional and national administrators withheld authorization for USDA staff at Pendleton to refill positions vacated by retirements of a chemist, an information technology specialist, and technical support staff for the soil microbiology and agronomy programs. Each of those positions are currently vacant. The chemistry laboratory is now operated by technical staff and visiting scientists in the soil chemistry research program, who also have responsibilities for research in the field. Soil microbiology, agronomy and soil science programs are operated primarily by the scientists in charge of those programs. Maintenance of computers and networks is now conducted through a contract with the Intermountain Educational Service District. Fortunately, additional positions appear to be forthcoming, including technical support for the two new USDA scientists who are likely to be hired during 2020.

Buildings and Facilities

Most of the buildings constructed from the 1930s to the 1980s, as described in Chapter 3, continue to be functional, efficient and well maintained. Numerous updates and modifications have been made as needs evolved and funds became available. This section briefly summarizes the status of buildings and facilities, and addresses current or anticipated modifications.

The primary office and laboratory building at Pendleton is owned and operated by the USDA-ARS. That building provides offices for all USDA employees and for OSU scientists and office staff. It also includes a conference room, computer servers and network hub, and printing and copying facilities. The primary building also includes laboratories for most USDA programs and for the OSU plant pathology and weed science programs. USDA laboratories include facilities for research on plant physiology, soil science, and hydrology, for analytical chemistry, for soil and plant drying, grinding and processing, and for fabrication, maintenance and storage of computers and experimental equipment. Additional USDA buildings include a machine shop for repair and fabrication of field and experimental equipment, several machine storage buildings, areas for processing plant and grain samples, and a soil microbiology laboratory. The microbiology laboratory is currently being renovated and enlarged, and facilities are being developed for the anticipated hiring of a plant physiologist. A fenced area is used to park, load and prepare equipment and vehicles.

The CBARC building complex at Pendleton consists of an office and laboratory building, barn, machine shop, machine shed, weather station, residential unit, apartment, two greenhouses with attached preparation and sampling facilities, farm manager's office, root-washing facility, fuel depot, and two pole barns. The office building includes five offices and a soil science laboratory. Until recently, that building also housed a large library of several dozen technical journals and several hundreds of reference books that had been purchased by OSU and USDA scientists since the 1930s. In 2015, the CBARC administrator shipped the entire library to a book recycler. That space is now used as a room for small meetings. The barn is used to store pesticides, fertilizers and seeds. A pesticide handling area is used to load pesticides into field equipment and to clean the equipment after use. The machine shop includes spaces for repairing equipment and vehicles, fabricating and painting field equipment, storing parts and supplies, and for working with wood. The same building includes laboratories for the statewide cereal testing program and the weed science program. Much of the farm and experimental field equipment are stored in the machine shed and pole barns. The pole barns also include enclosed rooms to store field and laboratory equipment, and to process grain samples. The greenhouse support facility includes work areas, controlled-environment chambers, and spaces for storing supplies.

All plant pathology work areas were renovated after 2017. Staff are currently attempting to identify a source of funds to construct on-station housing for visiting students and scientists, and to enclose additional bays of a pole barn, which will in turn lead to a new need for a facility to provide all-weather protection of equipment used for field research.

Structural facilities at the Sherman Station include a residential unit, recently constructed office building, machine shop, two equipment and vehicle storage buildings, weather station, and a newly constructed pesticide storage and handling facility. The office building includes a conference room and offices for the Sherman County Extension Service, the Sherman County Planner, and the Sherman Station Farm Manager. A new pesticide storage and handling facility was constructed during 2017.

Office and Laboratory Equipment

All federal and state offices and laboratories at Pendleton are equipped with computers and high-speed internet linkage. They also include specialized software for statistical analysis. Most are also capable of modeling fields or crops using geographic information systems, and some are capable of image processing and analysis.

USDA laboratories include grinding equipment and ovens to prepare plant and soil samples for analysis, and instruments to analyze samples of plants, soils and water. The chemistry laboratory includes a carbon/nitrogen/sulfur analyzer, atomic absorption analyzer, gas chromatograph, spectrophotometers, centrifuges, shakers and miscellaneous small equipment. The microbiology laboratory includes growth chambers, fluorescence spectrophotometer to analyze soil enzymes, fluorescence microscope with digital camera, and equipment for DNA/RNA extraction, gel electrophoresis, PCR (polymerase chain reaction), quantitative PCR (qPCR), DNA/RNA quantification by fluorescence or with a bioanalyzer, refrigerators, -20°C freezers, and a -80°C freezer. Additional growth chambers are being purchased for use by the new Crop Physiologist. Field data collection equipment includes crop canopy analyzers, spectral radiometers, chlorophyll meters, portable infrared gas analyzers, dielectric soil moisture probes, soil carbon dioxide probes, data loggers, infiltrometers, soil penetrometer, unmanned aerial vehicles for monitoring and analyzing field experiments, and remote weather stations.

The state laboratories include research equipment sufficient to operate modern programs in plant breeding, weed science, soil science and plant pathology. Plant breeding equipment includes capabilities for threshing single wheat heads, entire bundles of plants, and small- to medium-size field plots. That program also includes equipment to measure grain test weight and grain protein content. The weed science equipment includes an extensive array of sprayer types and sizes, and facilities to prepare and package the solutions. A specialty chamber houses equipment to apply precise dosages to plants grown in the greenhouse. Instruments mounted on a grain combine can be used to quantify the density of weeds, in real time, during the harvest operation. The soil science program includes equipment to monitor soil water content at various depths in soil, estimate and map soil depth while pulling an instrument across the field surface, monitor crop conditions using an unmanned aerial vehicle, and analyze soil nutrients in a chemistry laboratory. The plant pathology program includes equipment for viewing and culturing microscopic organisms, for preparing and distributing uniform culture of pathogenic organisms in greenhouse and field trials, for storing plants and organisms at -20°C, and for incubating plants under specified temperature and humidity to encourage disease development. All of these programs also use equipment for preparing plant and soil samples for analysis; including drying ovens, grinders, and facilities for storage of samples.

The CBARC shops at Moro and Pendleton are each equipped for maintaining and repairing vehicles and equipment. The shop at Pendleton is also equipped for fabricating and painting equipment, and for working with wood.

Field Equipment and Vehicles

Inventories of field equipment and vehicles are necessarily very large for both agencies. The required equipment is of various sizes to meet the demands of on- and off-station research trials, and the necessities for on-station general farming operations. The following statements depict major categories of equipment and vehicles currently operated and maintained.

State programs at Moro and Pendleton currently operate and maintain 15 vehicles, nine trailers, 24 tractors, 19 seed drills, and six grain combines. The vehicles include one sport utility vehicle (SUV), 11 pickups and three trucks. Tractors vary from small Kubota tractors to a Kubota M126X track-type tractor with precision-guidance instrumentation. Seed drills include small plot drills, several types of grain drills for general farming and larger experiments, a no-till range drill. Some drills have on-the-go capabilities to apply variable rates and formulations of fertilizers. The combines vary from small plot combines to a standard commercial-size combine at each station. Some equipment was acquired through grants by the Oregon Wheat Commission, Oregon Wheat Foundation, Sherman Station Endowment, and Oregon Agricultural Research Foundation.

The USDA program at Pendleton currently operates and maintains 11 vehicles, seven trailers, five tractors, five seed drills, and four combines. The vehicles include two sedans, one suburban, six pickups and two trucks. The equipment includes the same range of necessities described in the previous paragraph. Some equipment includes modern technologies, including combines with grain yield and quality sensors, and tractors with precision guidance. Utility vehicles and mobile GPS receivers provide mapping, guidance, and surveying capabilities.

There are, of course, requirements for many other types of field equipment at these stations. Some examples are various types, sizes and designs of equipment such as plows, discs, harrows, rod-weeders and others. There are also various sizes and styles of flail mowers, sprayers, 4-wheel roust-about vehicles, fork lifts, and mechanized probes for collecting soil samples.

New Projects and Funding Initiatives

The USDA Resilient Dryland Farming Initiative is a grower-conceived and grower-led program that was funded over a 5-year interval, from 2019 until 2024. It is coordinated by Dr. Catherine Reardon, and will provide $2 million annually for collaborative research conducted by USDA and CBARC scientists. Additional details were presented in Chapter 26.

CBARC recently became a formal member of the Soil Health Institute, which is a non-profit whose mission is to safeguard and enhance the vitality and productivity of soil through scientific research and advancement. The Institute identifies gaps in research and adoption, and develops networks and funding to address those gaps. The Institute is cataloguing long-term (≥ 10 years) agricultural experiments throughout North America. Long-term experiments at Pendleton receive a small amount of funding to support research instrumentation and collaborations. Dr. Stephen Machado coordinates local participation in that program.

Another new grower-led initiative seeks to establish the Pendleton Station as a 'Soil Carbon Center.' The center-of-excellence concept would capture, promote and expand the expertise already present and studying matters related to reserves and 'pools' of carbon-containing compounds in soil. These topics are of great importance to understandings of sustainable farming practices and changing climatic patterns. The structure and funding for this proposed center are in early stages of development.

Culture

It was stated earlier that the dryland research centers are vibrant and gaining strength. While true, and as has occurred throughout their history, changes in staff, administration and societal interests and needs also lead to evolutions of culture at the centers. Subtle changes during the past two decades have collectively introduced important shifts in operational efficiency and interpersonal relationships. A majority of staff from both agencies no longer mix and interact during coffee breaks and lunch periods. There are now very few joint-agency community service projects, almost no joint staff meetings, fewer social gatherings during evenings and weekends, fewer and less-inclusive summer picnics, and a lower level of attentiveness to the inclusion of retirees in on- and off-station events. The interagency year-end celebrations at an administrator's home have been terminated, after being a tradition from 1911 until 2014. Some of those reductions were partially offset by an increasing frequency of on-station potluck lunches during work days. From the author's perspective, these changes have collectively contributed to a reduction of camaraderie among employees within and between agencies. Likewise, at the community level, the past several years have been the first in nearly a century in which none of the station or center administrators have been a member of, and active in, the oldest and largest service club in the region. That is but one example of a reduced level of station recognition within the business and social culture of Pendleton. It will be of interest to determine if some of these cultural changes will prove to have been cyclic, and be reversed during further changes in leadership, personnel and practices.

This book is concluded by presenting a pictorial example of topics addressed in this chapter.

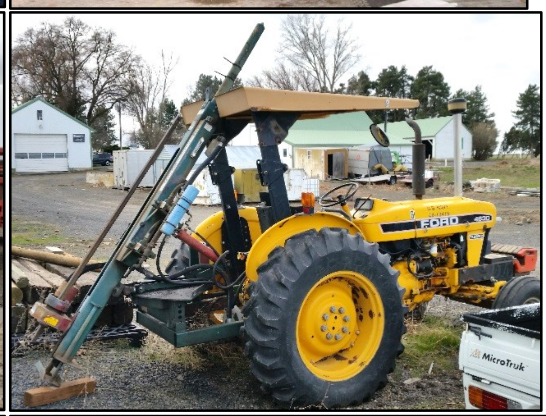
Facility and Staff







Equipment

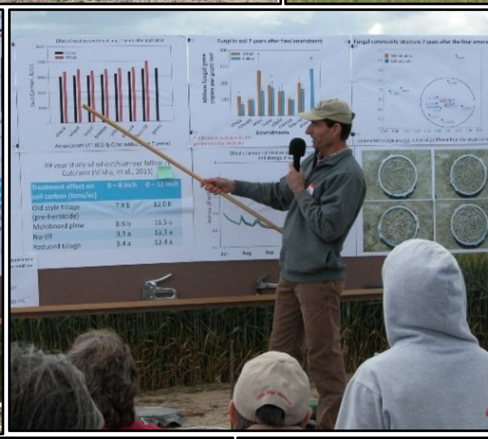


Equipment



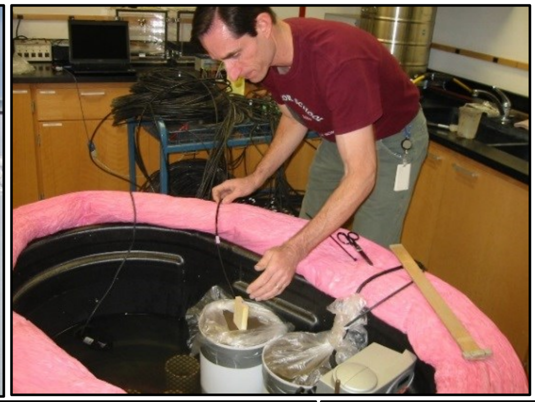



Field Days

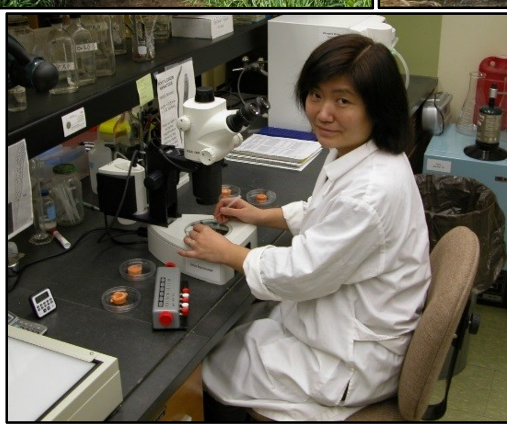


At Work

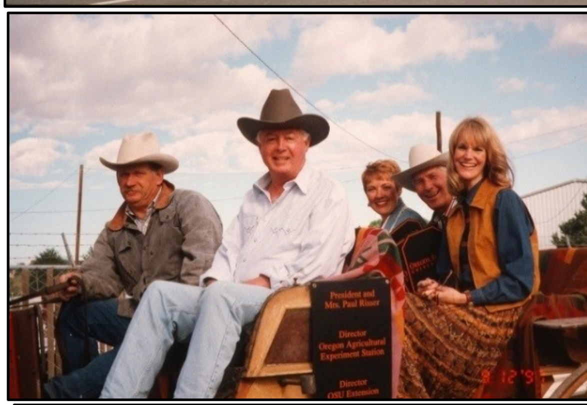
At Work






Social and Extracurricular



Social and Extracurricular

Chapter 30 - Epilogue

Activities that represented the work of the dryland experiment stations were summarized in this treatise. Hundreds of equally noteworthy experiments were not mentioned. Likewise, numerous little-mentioned but highly-skilled technical staff, students and visiting scientists made immensely important contributions that could not be summarized. Those contributions included preparing experimental designs and protocols that fulfilled the objectives of the scientists, and the visualization and fabrication of equipment to meet those experimental needs. Omission of those many contributions occurred only to limit the length of this book.

Also, this summary addressed the human component of work at the stations in a very superficial manner. It did not delve into most of the human interactions and daily activities of the employees. Some stories are complex, lengthy or controversial. A few are mentioned in this epilogue to briefly illustrate that facet of activities at the stations.

There have been many opportunities and challenges associated with interactions among personnel. Disputes among administrators were sometimes mentioned in earlier chapters. Unmentioned earlier was a shouting match between agency administrators that led each agency to re-direct those involved; one agency retired their local administrator, and the other agency transferred their administrator to a different location. There have been other incidents that required intervention by a station administrator. Some resulted from occasional loves or animosities between pairs or groups of employees. Formal oversight by the university and a labor union became required when a supervisor and an employee disagreed over one another's perceptions of the employee's level of supervisory responsibility. There were also formal oversights by the university and it's Office of Personnel regarding charges of sexual harassment; one regarding a woman's complaint about a man, and one about a woman's complaint about another woman. Administrative oversight became required to address a claim by one employee that another employee was doing his job in an irresponsible manner. At a different time, there was an employee made what appeared to be false statements to the public about the work skills of another employee.

Likewise, the workplace has not been devoid of opportunities for politics to affect activities and decisions. Several examples were cited in the chapter on livestock. But there have also been more recent examples. The alignment of powerful farmers and a Corvallis-based university scientist created an unduly negative influence regarding a tenure decision for a promising young scientist at Pendleton. That scientist's research progress was perceived as a competitive threat to the more powerful scientist at Corvallis, who controlled a strong affiliation between an influential commodity commission and a number of university research programs. That incident resulted in the younger scientist being removed from the university. There have also been other occasions in which university decisions regarding the employment status of scientists have been influenced by viewpoints of growers and a commodity commission. In one case, grower input strongly influenced and expedited a university decision to invite a scientist at Pendleton to seek employment elsewhere, because tenure was unlikely to be forthcoming for that individual. On another occasion, a backlash by those same groups successfully reversed a university decision to remove a scientist. A final example reflects results of a research project in which an OSU scientist and an ARS scientist collaborated to model the possibilility that a pathogen which was new to the USA could become established in the Pacific Northwest if it were to be inadvertently introduced into our region. The research revealed that the pathogen could survive and thrive in several distinct areas of Oregon and Washington. When the results were prepared for publication, high-level USDA administrators forbid the ARS scientist from publishing that information. They did not question the results, but considered those results to be politically volatile. It was thought that the information could possibly affect the wheat export trade. The ARS scientist's name was removed from the authorship and the paper was published by the OSU scientist. The procedures used for that work at Pendleton are now cited by international scientists who model conditions required for establishment of the karnal bunt pathogen – but there is no mention of contributions by the ARS scientist who provided key procedures for conducting that research.

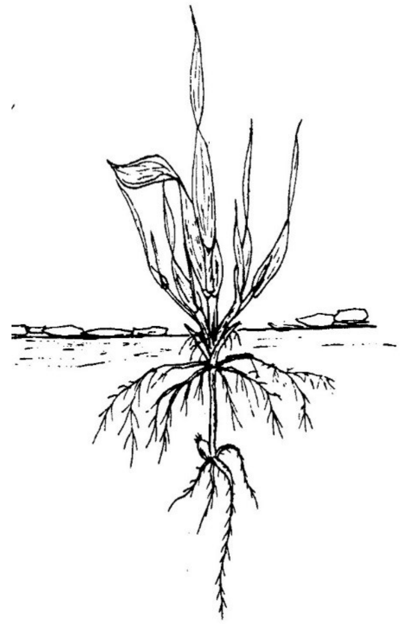
There have been numerous 'incidents' and a few accidents involving employees, vehicles and equipment. Several deer were hit when staff members were traveling during dust or dawn. A heavily-laden tandem-axle trailer lost both tires from one side of one axle while moving at road speed on a two-lane road. Shortly before the tires broke loose, a large lug nut had smashed through the windshield of an oncoming vehicle, spraying glass onto that driver. An employee was once responsible for a hit-and-run fender-bender in a downtown parking lot. One wheel of a plot combine once fell off the trailer ramp during an unloading incident. There have been numerous flat tires on trucks and trailers at remote locations. A mechanic once installed the rocker arms for a tandem-axle trailer upside down, leading to an incident in which the frame of the heavily-loaded trailer dropped onto and melted the tires while enroute to a distant location. And it happened again, but without burning the tires, on the return trip, at which time the root cause was identified as improperly replaced springs and shackles. A truck blew its turbo when it was 500 miles from home base. On another trip, the turbo blew again, on a narrow two-lane road 100 miles from the station. A truck and heavily laden trailer lost traction and became stationary on a dark, steep, ice-covered tight curve of a 2-lane road during a non-predicted, out-of-season, nighttime snowstorm in western Morrow County. An ignition switch failed on a pickup that was midway between Pendleton and Corvallis. A 'really' temporary employee accidentally discharged a pistol in the men's bathroom of the USDA office building, resulting in a hole through the doors of the stall and a built-in storage cabinet. An electrical short inside a state-owned combine ignited a commercial field and threatened the residence and barns of the collaborator. A truck-mounted soil probe became immobilized while the probe was buried to a depth of six feet at a remote location. The truck slipped sideways, which jammed and bent the probe. None of the equipment could be moved until the probe was dug completely out using the single shovel that was available. A number of rear-drive vehicles became stuck in remote locations. A car became buried in the seemingly bottomless 'bull dust' of volcanic ash following truck traffic during harvest. A pickup became stalled on wet grass on a hillside during a dewy morning. A pickup became stuck on a nearly level field road shortly after the onset of a light rain shower. Other pickups became stuck in deeply cultivated summer fallow, in deep snow near a remote experimental site, and in deep mud. Keys have been locked into several vehicles. At one remote experimental site, but far from any home, a scientist changed clothing to take field notes while enroute home from a meeting. He left the keys and telephone in the dress slacks that were placed into the trunk of the sedan. After removing the back seat, and a long hike that resulted in finding some barbed wire, the slacks were 'fished' out of the trunk.

Some incidents became bureaucratic nightmares. A scientist once improperly loaned a heavy no-till seed drill to a farmer. They loaded it on the farmer's truck and, when the truck farmer turned onto a freeway entrance at the top of a hill, the drill fell off the truck, passed through the fence, and became lodged on a hillside near a residential neighborhood in Pendleton. On another occasion, a truck hitch became separated on a rural highway, dropping the trailer hitch onto the roadway and gouging several 1-inch deep strips as the truck pulled off the roadway. The Oregon Department of Transportation tried repeatedly, but failed, to extract an exorbitant amount of money from the station to transport construction equipment from southern Oregon to resurface an entire section of highway. On another occasion, the chairman of the Pendleton Station Liaison Committee conspired with a friend in North Dakota to transfer a Yielder No-Till drill from an experiment station in North Dakota to the Pendleton Station. They felt the drill was not being used in North Dakota and would be an important addition to programs in Oregon. The drill was owned by the Tennessee Valley Authority. The transfer was done without knowledge or authorization by the drill's owner, the drill's recipient, or the experiment station from which it was removed. The drill did in fact become valuable for no-till research and demonstrations in Oregon (see Chapter 19). However, immense amounts of paper work, over a long time period, and involving attorneys from each agency, were required to rectify that 'loan.' The loan called for the Station to return the drill to TVA headquarters, near Muscle Shoals, Alabama, when it was no longer needed or whenever the TVA wanted it back. After many years of effective use, additional negotiations were required to allow the Pendleton Station to sell the drill to a farmer in nearby Washington.

Some other types of activities also fall into the category of "just get 'er' done." And some of those tales are best left untold. But some provide insights into benefits of being at a station located 300 miles from Corvallis. For example, a building with heat and water was constructed without being authorized and planned by the Experiment Station architect. Similarly, a 3-room office building with bathroom and shower facilities was purchased from a used car dealer in Walla Walla and installed at the Pendleton Station, without notifying the OAES architect. Those buildings now have official experiment station numbers. Money was often very limited during the 1980s and 1990s. Instead of hiring an engineer from Portland, a station scientist prepared the environmental impact statement that needed to be certified and approved by federal auditors from Washington, D.C. before a new greenhouse facility could be constructed using funds from a federal appropriation. Likewise, a station scientist rather than a certified engineer also wrote the spill prevention and containment plan for a new fuel depot; that plan was approved by the university and State Fire Marshall, neither of which knew who actually wrote the plan.

A temporary employee was once given a choice to either return an electric drill he stole the previous day, or to not receive payment for his work; his failure of that employee to respond was met by a commensurate failure of the CBARC administrator to submit his time sheet. An even trade! When the Sherman Station Liaison Committee was purchasing a tractor for the station, the Committee had funds for only the first of two payments. The donation came close to failing because the university refused to guarantee the Committee's final payment one year later. The issue was resolved when the station superintendent (this author) signed the promissory note, as a private individual, to guarantee the second payment. Likewise, a statewide auction of surplus public vehicles and equipment was once held at the Pendleton Station. Perhaps a thousand items were trucked in from around the state. Donations were also accepted. Profit from the sale was designated for the state coffers. A donated item included a John Deere 55H combine. When the equipment sales were faltering due to a sparsity of bidders, the station superintendent (this author) prompted his wife to purchase the combine, knowing it wouldn't fit into the small backyard of their home in Pendleton. After a required waiting period, the combine was resold and transported to a farm near The Dalles, with the profit being donated to the station.

These are just some of the activities that could be told about life and work at the dryland experiment stations. More elaborate explanations for some of these topics will probably be lost forever, as they should be!



Appendix 1 – List of Administrators: 1909-2020

Sherman Experiment Station: (Superintendents*, employing agency, and discipline)

1909-1910	1 yr	Mr. Harry J. C. Umberger (USDA)	'pre-superintendent'
1910-1911	1 yr	Mr. Harry J. C. Umberger (USDA)	agronomist
1912-1938	25 yr	Mr. David E. Stephens (USDA)	agronomist
1938-1948	9 yr	Mr. Merrill M. Oveson (USDA)	agronomist
1949-1953	4 yr	Mr. George A. Mitchell (USDA)	agronomist
1953-1964	11 yr	Mr. William E. Hall (USDA/OSU)	agronomist
1964-1973	10 yr	Mr. Jack T. McDermid (OSU)	agronomist

Pendleton Experiment Station: (Superintendents*, employing agency, and discipline)

1928-1938	10 yr	Mr. David E. Stephens (USDA)	wheat breeder
1938-1948	10 yr	Mr. George A. Mitchell (USDA/OSU)	agronomist
1948-1966	18 yr	Mr. Merrill M. Oveson (USDA/OSU)	agronomist
1966-1973	7 yr	Dr. Charles R. Rohde (OSU)	wheat breeder

Columbia Basin Agricultural Research Center:** (Superintendents/Directors*; all OSU)

1973-1975	2 yr	Dr. Charles R. Rohde	wheat breeder
1975-1984	10 yr	Dr. Steve Lund	plant breeder
1985	<1 yr	Mr. Mathias Kolding (interim)	plant breeder
1985-2000	16 yr	Dr. Richard W. Smiley	plant pathologist
2000-2013	13 yr	Dr. Steven E. Petrie	soil scientist
2013-2014	1.5 yr	Dr. Stephen Machado (interim)	agronomist
2014-2015	<1 yr	Dr. Valtcho Jeliazkov	agronomist
2015-2020	5 yr	Ms. Mary K. Corp	extensionist

Columbia Plateau Conservation Research Center*:** (Research Leaders; all USDA)

1970-1972	2 yr	Dr. Robert E. Ramig	soil scientist
1972-1984	14 yr	Dr. Raymond R. Allmaras	soil scientist
1985-1996	11 yr	Dr. E. L. (Betty) Klepper	plant physiologist
1996-2003	7 yr	Dr. Dale E. Wilkins	agricultural engineer
2003-2004	1 yr	Dr. Stephan L. Albrecht (acting)	soil microbiologist
2004-2020	16 yr	Dr. Daniel S. Long	agronomist
2020	?	Dr. Stewart Wuest	soil scientist

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*Administrators of the Sherman and Pendleton Stations, and the Columbia Basin Agricultural Research Center, carried the title of Superintendent until the early 2000s, at which time the title was changed to Director.

**The Columbia Basin Agricultural Research Center was formed in 1973 by merging the OSU branch stations at Pendleton, Moro, and Hermiston. The Hermiston station was separated from this linkage during 1975.

***The Columbia Plateau Conservation Research Center was established as a separate unit of the USDA-Agricultural Research Service during 1970.

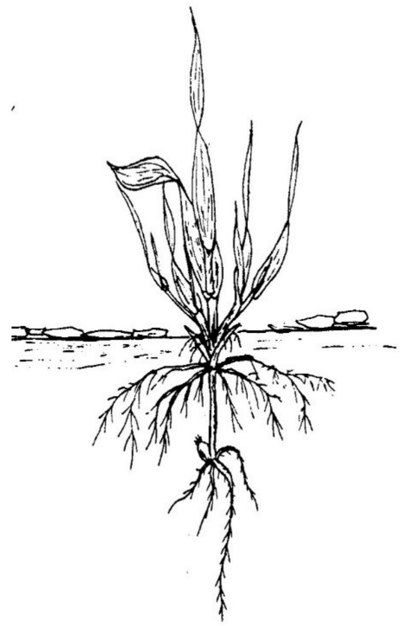
Appendix 2 – List of Scientists and Extensionists: 1909-2020

Scientists listed by name, location, primary employing agency, disciplinary expertise, years of service, and numbers of technical publications ('Pubs', from 1909-2019, as shown in Appendix 3) and 'Special Reports' (SRs, from 1976-2010, as shown in Appendix 4; 'na' means the SR series was not produced during the period of employment for that individual). Primary agencies were U.S. Department of Agriculture (USDA), Oregon Agricultural Experiment Station (AES), Oregon Extension Service (ES), or joint employment by USDA and AES (both).

Scientist	Location	Agency	Discipline	Years	Pubs	SRs
Mr. Theodore R. Horning	Pendleton	USDA	Agricultural Engineer	1949-1964	2	na
Mr. John Slosser	Pendleton	USDA	Agricultural Engineer	1955-1957	0	na
Dr. Clarence E. Johnson	Pendleton	USDA	Agricultural Engineer	1977-1979	11	0
Mr. Gerald O. George	Pendleton	USDA	Agricultural Engineer	1978-1980	1	0
Dr. Dale E. Wilkins	Pendleton	USDA	Agricultural Engineer	1979-2003	62	28
Dr. Mark C. Siemens	Pendleton	USDA	Agricultural Engineer	2003-2008	14	5
Mr. Harry J. C. Umberger	Moro	USDA	Agronomist	1909-1911	0	na
Mr. David E. Stephens	Moro	both	Agronomist	1912-1938	24	na
Mr. C. Edwin Hill	Moro	USDA	Agronomist	1912-1918	0	na
Mr. W. S. Carpenter	Moro	USDA	Agronomist	1919	0	na
Mr. George A. Mitchell	Moro	AES	Agronomist	1921-1928	4	na
"	Pendleton	USDA	Agronomist	1928-1948		
Mr. Merrill M. Oveson	Moro	AES	Agronomist	1929-1938		
"	"	both	"	1938-1948	16	na
"	Pendleton	both	"	1948-1966		
Mr. Jack T. McDermid	Pendleton	USDA	Agronomist	1943-1944	0	na
"	Moro	"	"	1964-1973		
Mr. Carroll H. Ramage	Pendleton	USDA	Agronomist	1943-1950	0	na
Mr. William E. Hall	Moro	AES	Agronomist	1947-1964	16	na
Mr. H. Marr Waddoups	Pendleton	AES	Agronomist	1951-1956	6	na
Mr. Laurn K. Beutler	Pendleton	AES	Agronomist	1956-1957	2	na
Mr. Roland K. Schwanke	Pendleton	AES	Agronomist	1968-1969	1	na
Mr. F. Vance Pumphrey	Pendleton	AES	Agronomist	1970-1985	21	1
Dr. Thomas G. Chastain	Pendleton	AES	Agronomist	1989-1992	16	4
Dr. William A. Payne	Pendleton	AES	Agronomist	1996-1999	19	6
Dr. Stephen J. Machado, Sr.	Pendleton	AES	Agronomist	2001-	48	14
Dr. Daniel S. Long	Pendleton	USDA	Agronomist	2004-2020	34	2
Dr. Valtcho D. Jeliazkov	Pendleton	AES	Agronomist	2014-2015	6	na
Mr. Fred Hagelstein	Pendleton	ES	Extension Area Super.	1973-1974	0	na
Mr. Bruce Mackey	Pendleton	ES	Ext. Community Devel.	1974	0	na
Mr. Darrell C. Maxwell	Pendleton	ES	Extension Agronomist	1982-1985	3	1
Dr. Donald J. Wysocki	Pendleton	ES	Extension Soil Scientist	1985-	41	21
Ms. Mary K. Corp	Pendleton	AES/ES	Extension Agriculturalist	2015-2020	13	4
Dr. John F. Zuzel	Pendleton	USDA	Hydrologist	1979-1995	36	6
Dr. John D. Williams	Pendleton	USDA	Hydrologist	1995-	38	9
Dr. Richard W. Smiley	Pendleton	AES	Plant Pathologist	1985-2015	152	44
Dr. Christina H. Hagerty	Pendleton	AES	Plant Pathologist	2016-	10	na
Mr. Donald W. George	Pendleton	USDA	Plant Physiologist	1954-1965	2	na
Dr. E. (Betty) L. Klepper	Pendleton	USDA	Plant Physiologist	1976-1996	80	7
Dr. Harold P. Collins	Pendleton	USDA	Soil Microbiol.	1987-1991	14	2
Dr. Stephan L. Albrecht	Pendleton	USDA	Soil Microbiol.	1992-2009	35	23
Dr. Catherine L. Reardon	Pendleton	USDA	Soil Microbiol.	2010-	28	na
Mr. F. J. Schneiderhan	Moro	USDA	Cereal Breeder	1916-1917	0	na
Mr. J. A. Clark	Moro	USDA	Cereal Breeder	1919	1	na
Mr. Burton B. Bayles	Moro	USDA	Cereal Breeder	1923-1926	4	na
James Foster Martin	Moro	USDA	Cereal Breeder	1927-1930		na

Dr. James Foster Martin	Pendleton	USDA	Cereal Breeder	1931-1950	8	na
Mr. Robert B. Webb	Moro	USDA	Cereal Breeder	1930-1936	0	na
Mr. Robert W. Henderson	Moro	USDA	Cereal Breeder	1938	0	na
Mr. Leon B. Hubbard	Moro	USDA	Cereal Breeder	1941-1942	0	na
Mr. O. S. Weaver	Moro	USDA	Cereal Breeder	1943-1944	0	na
Dr. Orville A. Vogel	Pullman	USDA	Cereal Breeder	1944-1951	?	na
Mr. Francis H. McNeal	Pendleton	USDA	Cereal Breeder	1947-1948	0	na
Dr. Charles R. Rohde “	Pendleton “	both AES	Cereal Breeder “	1952-1956 1956-1987	27	1
Mr. Mathias F. Kolding	Pendleton	AES	Cereal Breeder	1971-1985	12	0
Dr. Steve Lund	Pendleton	AES	Cereal Breeder	1975-1985	0	0
Dr. Pamela K. Zwer	Pendleton	AES	Cereal Breeder	1988-1994	17	6
Dr. Warren E. Kronstad	Corvallis	OAED	Cereal Breeder	1995-1996	17	40
Dr. Kimberly Garland-Campbell	Pullman	USDA	Cereal Breeder	1996-2006	9	22
Dr. Ryan Graebner	Pendleton	AES	Cereal Testing	2018-	1	na
Mr. Joseph Belanger "	Moro Pendleton	USDA “	Soil Scientist “	1938-1939 1940-1943	0	na
Dr. Cleveland J. Gerard	Pendleton	both	Soil Scientist	1954-1957	5	na
Mr. W. F. Wright	Moro	AES	Soil Scientist	1957-1958	0	na
Dr. Charles M. Smith	Pendleton	USDA	Soil Scientist	1957-1961	2	na
Dr. Robert E. Ramig	Pendleton	USDA	Soil Scientist	1961-1990	28	3
Mr. Donald Graham	Moro	AES	Soil Scientist	1962-1963	0	na
Dr. Ronald W. Rickman	Pendleton	USDA	Soil Scientist	1969-2001	82	15
Dr. Raymond R. Allmaras	Pendleton	USDA	Soil Scientist	1971-1984	60	1
Mr. Paul E. Rasmussen	Pendleton	USDA	Soil Scientist	1971-1999	67	16
Dr. Clyde L. Douglas, Jr.	Pendleton	USDA	Soil Scientist	1975-2001	48	21
Dr. Joseph L. Pikul, Jr.	Pendleton	USDA	Soil Scientist	1976-1991	30	2
Dr. Stewart B. Wuest	Pendleton	USDA	Soil Scientist	1999-	49	10
Dr. Steve E. Petrie	Pendleton	AES	Soil Scientist	2000-2013	20	21
Dr. Hero T. Gollany	Pendleton	USDA	Soil Scientist	2001-	44	4
Mr. David E. Bayer	Pendleton	AES	Weed Scientist	1953-1954	0	na
Dr. Dean G. Swan “	Pendleton “	AES “	Weed Scientist “	1955-1962 1964-1965	3	na
Dr. Arnold P. Appleby	Pendleton	AES	Weed Scientist	1962-1963	1	na
Dr. Donald J. Rydrych	Pendleton	AES	Weed Scientist	1965-1990	8	2
Dr. Daniel A. Ball	Pendleton	AES	Weed Scientist	1991-2013	56	17
Dr. Judit Barroso Perez	Pendleton	AES	Weed Scientist	2014-	14	na

These scientists and extensionists were local leaders for what Kirby Brumfeld called a ‘small army.’ He stated “*Wheat has gained its ranking as number one farm crop of the Northwest in spite of weeds, pest and disease. … On the farmers’ side though has been a small army of dedicated agronomists, entomologist and pathologists. Some of these specialists are employed by private industry but most have worked under the banners of land grant universities and the United States Department of Agriculture. … In some ways the most unenviable job in the world is that of a plant scientist. He does not know what it is to taste absolute and complete success. … State specialists and county agents feed up-to-the-minute facts and information to farmers as soon as researchers make a new advance in the technology of wheat.*” (Excerpts from Kirby Brumfeld. 1968. This Was Wheat Farming. Bonanza Books. New York. 191 pages)



Appendix 3 – List of Technical Publications: 1909-2019

Between 1909 and early 2020, scientists at the Sherman Branch Experiment Station, Pendleton Branch Experiment Station, Columbia Basin Agricultural Research Center, and Columbia Plateau Conservation Research Center have published the following list of 926 peer-reviewed technical papers, book chapters, extension bulletins and patents. While extensive, this list is also presumed to be incomplete. Five included publications were by authors who were not located at these stations and centers; Hunter (1918), Hunter (1927), Jones and Yates (1924), Mathews (1951), and Engle and Harston (1975). Much of the data and conclusions in those five publications were directly attributed to research conducted at the Sherman or Pendleton stations. Also, a few older, well-prepared but unpublished educational summaries were included to represent selected historical perspectives. This list does not include 180 publications published in the research center's 'Special Report' series from 1976 to 2010. They are listed in Appendix 4 because they were not validated through an authentic peer-review process. Also excluded from this list because they lacked authentication by peer-review were an exceedingly large number of abstracts and posters presented at professional and industry conferences, and an amazingly high number of articles published in newspapers and industry trade magazines. Likewise, large numbers of peer-reviewed reports were published in professional journals but were excluded from this book because they reported mostly single-year tests of fungicides, nematicides, herbicides, or of screenings of plant varieties.

(*last updated on February 27, 2020*)

Akbari, A. 1986. Risk analysis of alternative tillage systems in North Central Oregon dryland wheat production. Ph.D. Thesis. Oregon State University, Corvallis. 285 pages.

Al Mutlaq, K. F., C. Mallory-Smith, and D. A. Ball. 2003. Procarbazone-sodium effect on rotational crops and its dissipation in soils. Pages 5-29. In: Research Bulletin No. 120, Agricultural Research Center, King Saud University. Riyadh, Saudi Arabia.

Alban, L. A., and H. E. Cushman, 1962. Fertilizer recommendations for wheat in the Columbia Basin of Oregon. Oregon Cooperative Extension Service Bulletin 806. 14 pages.

Albrecht, S. L. 1994. Non-symbiotic nitrogen fixation. Pages 337-343. In: Physiology and determination of crop yield (K. J. Boote, J. M. Bennett, T. R. Sinclair, and G. M. Paulsen, editors). American Society of Agronomy, Madison, WI.

Albrecht, S. L. 1997. Eukaryotic algae and cyanobacteria. Pages 94-114. In: Principles and applications of microbiology (D. M. Sylvia, Fuhrmann, P. G. Hartel, and D. A. Zuberer, editors). Prentice Hall, Upper Saddle River, NJ.

Albrecht, S. L., C. L. Douglas, Jr., E. L. Klepper, P. E. Rasmussen, R. W. Rickman, R. W. Smiley, D. E. Wilkins, and D. J. Wysocki. 1995. Effects of foliar methanol applications on crop yield. Crop Science 35:1642-1646.

Allen, L. H., Jr., S. L. Albrecht, W. Colon, and S. A. Covell. 1994. Effects of carbon dioxide and temperature on methane emission of rice. International Rice Research Notes 19:43-44.

Allen, L. H., Jr., S. L. Albrecht, W. Colón-Guasp, S. A. Covell, J. T. Baker, D. Pan, and K. J. Boote. 2004. Methane emissions of rice increased by elevated CO2 and temperature. Journal of Environmental Quality 32:1978-1991.

Allmaras, R. R. 1983. Soil conservation: Using climate, soils, topography, and adapted crops information on selected conservation practices. Pages 139-153. In: Dryland Agriculture in North America. ASA Monograph 23, American Society of Agronomy, Madison, WI.

Allmaras, R. R., P. M. Burford, J. L. Pikul, Jr., and D. E. Wilkins. 1988a. Tillage tool influences in incorporated wheat residue. p. 445-450. In Proc. of Int. Soil and Tillage Res. Org., Edinburgh, Scotland.

Allmaras, R. R., C. L. Douglas, Jr., P. E. Rasmussen, and L. L. Baarstad. 1985a. Distribution of small grain residue produced by combines. Agronomy Journal 77:730-734.

Allmaras, R. R., and R. H. Dowdy. 1985. Conservation tillage systems and their adoption in the United States. Soil and Tillage Research 5:197-222.

Allmaras, R. R., S. C. Gupta, J. L. Pikul, Jr., and C. E. Johnson. 1979. Tillage and plant residue management for control of soil erosion by water in agricultural lands of eastern Oregon. Journal of Soil and Water Conservation 34:85-90.

Allmaras, R. R., S. C. Gupta, J. L. Pikul, Jr., and C. E. Johnson. 1980. Soil erosion by water as related to management of tillage and surface residues, terracing, and contouring in eastern Oregon. USDA-SEA ARR-W-10. p. 53.

Allmaras, R. R., J. M. Kraft, and D. E. Miller. 1988b. Effects of soil compaction and incorporated residue on root health. Annual Review of Phytopathology 26:219-234.

Allmaras, R. R., J. M. Kraft, and J. L. Pikul, Jr. 1987. Lime and gypsum effects on pea-root-pathogen inoculum and related factors in a wheat-peas rotation. Agronomy Journal 79:439-445.

Allmaras, R. R., and W. W. Nelson. 1971. Corn (*Zea mays*) root configuration as influenced by row-interrow variants of tillage and straw mulch management. Soil Science Society of America Proceedings 35:974-980.

Allmaras, R. R., J. L. Pikul, Jr., C. L., Douglas, Jr., and R. W. Rickman. 1997. Temporal character of surface seal/crust: Influences of tillage and crop residue. Pages 171-188. In: Real World Infiltration (L. R Ahuja and A. Garrison, editors), Proceedings of a USDA-ARS Workshop, Pingree Park, CO July 22-25, 1996. Info Series #86 Colorado Water Resources Research Institute.

Allmaras, R. R., J. L. Pikul, Jr., J. M. Kraft, and D. E. Wilkins. 1988c. A method for measuring incorporated residue and associated soil properties. Soil Science Society of America Journal 52:1128-1133.

Allmaras, R. R., R. W. Rickman, L. G. Ekin, and B. A. Kimball. 1977. Chiseling influences on soil hydraulic properties. Soil Science Society of America Journal 41:796-803.

Allmaras, R. R., H. H. Schomberg, C. L. Douglas, Jr. and T. H. Dao. 2000. Soil organic carbon sequestration potential of adopting conservation tillage in U.S. croplands. Journal of Soil and Water Conservation 55:365-373.

Allmaras, R. R., P. W. Unger, and D. E. Wilkins. 1985b. Conservation tillage systems and soil productivity. Chapter 21. Pages 357-412. In: Soil Erosion and Crop Productivity (R. F. Follett and B. A Steward, editors). American Society of Agronomy, Madison, WI.

Allmaras, R. R., K. Ward, C. L. Douglas, Jr., and L. G. Ekin. 1982. Long-term cultivation effects on hydraulic properties of a Walla Walla silt loam. Soil and Tillage Research 2:265-279.

Allmaras, R. R., D. E. Wilkins, O. C. Burnside, and D. J. Mulla. 1998. Agricultural technology and adoption of conservation practices. Pages 99-157. In: Advances in soil and water conservation (F. J. Pierce and W. W. Frye, editors). Ann Arbor Press, Chelsea, MI.

Anderson, R., E. Zakarison, D. Ball, G. Wicks, D. Lyon, S. W. McDonald, S. Miller, F. Young and T. White. 2002. Jointed goatgrass: Ecology. Pacific Northwest Extension Publication EB1932. Washington State University. 8 pages.

Ankathi, S. K., D.S. Long, H. T. Gollany, P. Prajesh, and D. Shonnard. 2018. Life cycle assessments of oilseed crops produced in rotation with dryland cereals in the inland Pacific Northwest. International Journal of Life Cycle Assessment. 24:627-641.

Appleby, A. P., W. E. Kronstad, and C. R. Rohde. 1966. Influence of 2-chlorethytrimethylammonium chloride (CCC) on wheat *(Triticum aestivum* L.) when applied as a seed treatment. Agronomy Journal 58:435-437.

Armah-Agyeman, G., J. Loiland, R. Karow, and W. A. Payne. 2013. Dryland cropping systems: Grain sorghum. Oregon State University Extension Publication EM8794. 5 pages.

Auld, D. L., G. A. Murray, and F. V. Pumphrey. 1987. Alternate crops in conservation tillage systems. p. 137-158. In (L. F. Elliott, editor) STEEP-Soil Conservation Concepts and Accomplishments. Washington State Univ. Pullman, WA

Awale, R., M. A. Emeson, and S. Machado. 2017. Soil organic carbon pools as early indicators for soil organic matter stock changes under different tillage practices in inland Pacific Northwest. Frontiers in Ecology and Evolution 5:96. (doi: 10.3389/fevo.2017.00096)

Awale, R., S. Machado, R. Ghimire, P. Bista. 2017. Soil health. Pages 47-97. In: Advances in Dryland Farming in the Inland Pacific Northwest (G. Yorgey and C. Kruger, editors). Washington State University, Pullman, WA. 614 pages.

Awale, R., S. Machado, and K. Rhinhart. 2018. Soil carbon, nitrogen, pH, and crop yields in winter wheat-spring pea systems. Agronomy Journal 110:1523-1531.

Baarstad, L. L., R. W. Rickman, D. Wilkins, and S. Morita. 1993. A hydraulic soil sampler providing minimum field plot disturbance. Agronomy Journal 85:178-181.

Back, W. B., and J. Nairn. 1955. Alternatives of Using a Half Million Diverted Acres in Columbia Basin Counties of Oregon. Agricultural Experiment Station Circular of Information 552. Oregon State College, Corvallis. 7 pages.

Baker, D. N., F. D. Whisler, W. J. Parton, B. Klepper, C. V. Cole, W. O. Willis, D. E. Smika, A. L. Black, and A. Bauer. 1985. The development of winter wheat: A physical physiological process model. Pages 176-187. In: ARS Wheat Yield Project (W. O. Willis, editor). USDA, ARS ARS-38.

Baker, J. T., S. L. Albrecht, D. Pan, L. H. Allen, Jr., N. B. Pickering, and K. J. Boote. 1994. Carbon dioxide and temperature effects on rice (*Oryza sativa* L., cv. IR-72). Soil and Crop Science Society of Florida Proceedings 53:90-97.

Ball, D. A 1992. Weed seedbank response to tillage, herbicides, and crop rotation sequence. Weed Science 40:654-659.

Ball, D. A. 2014. Effects of aminocyclopyrachlor herbicide on downy brome (*Bromus tectorum*) seed production under field conditions. Invasive Plant Science and Management 7:561-564.

Ball, D. A., S. M. Frost, and L. H. Bennett. 2007a. ACCase-inhibitor herbicide resistance in downy brome (*Bromus tectorum*) in Oregon. Weed Science 55:91-94.

Ball, D. A., S. M. Frost, L. H. Bennett, D. C. Thill, T. Rauch, E. Jemmett, C. Mallory-Smith, C. Cole, J. P. Yenish, and R. Rood. 2007b. Control of rattail fescue (*Vulpia myuros*) in winter wheat. Weed Technology 21:583-590.

Ball, D. A., S. M. Frost, L. Fandrich, C. Tarasoff, and C. Mallory-Smith. 2008. Biological attributes of rattail fescue (*Vulpia myuros*). Weed Science 56:26-31.

Ball, D. A., S. M. Frost, and A. I. Gitelman. 2004. Predicting timing of downy brome (*Bromus tectorum*) seed production using growing degree-days. Weed Science 52:518- 524.

Ball, D. A., and A. G. Hulting. 2009. Rattail Fescue Biology and Management in Pacific Northwest Wheat Cropping Systems. Pacific Northwest Extension Publication PNW 613. 8 pages.

Ball, D. A., B. Klepper, and D. J. Rydrych. 1995. Comparative above-ground development rates for several annual grass weeds and cereal grains. Weed Science 43:410-416.

Ball, D. A, and S. D. Miller. 1993. Cropping history, tillage, and herbicide effects on weed flora composition in irrigated corn. Agronomy Journal 85:817-821.

Ball, D. A., A. G. Ogg, Jr., and P. M. Chevalier. 1997. The influence of seeding rate on weed control in small-red lentil. Weed Science 45:296-300.

Ball, D. A., A. G. Ogg, Jr., and F. L. Young. 1999a. Selective control of jointed goatgrass (*Aegilops cylindrica*) with imazamox in herbicide-resistant wheat. Weed Technology 13:77-82.

Ball, D. A., R. Parker, J. Colquhoun, and I. Dami. 2014. Preventing Herbicide Drift and Injury to Grapes. Oregon State University Extension Publication EM 8860. 8 pages.

Ball, D. A., and C. J. Peterson. 2007. Herbicide tolerance in imidazolinone-resistant wheat for weed management in the Pacific Northwest U.S.A. Pages 243-250. In: Wheat Production in Stressed Environments. (H. T. Buck, J. E. Nisi, and N. Salomón, editors). Springer. The Netherlands. 794 pages.

Ball, D., D. Rydrych, and B. Klepper. 1993. Relationship between growing degree days and development rate for jointed goatgrass and several other winter annual grasses and cereals. Pages 60-63. In: Jointed Goatgrass: A Threat to U. S. Wheat (P. Westra and R. Anderson, editors). Proceedings of the Jointed Goatgrass Symposium, Denver, CO.

Ball, D. A. and M. J. Shaffer. 1993. Simulating resource competition in multispecies agricultural plant communities. Weed Research 35:299-310.

Ball, D. A., D. L. Walenta, and P. E. Rasmussen. 1998. Impact of nitrogen fertilization and stubble burning on the downy brome seedbank in a winter wheat- fallow rotation. Journal of Production Agriculture 11:342-344.

Ball, D. A., D. J. Wysocki, and T. G. Chastain. 1996. Nitrogen application timing effects on downy brome and winter wheat growth and yield. Weed Technology 10:305-310.

Ball, D. A, J. P. Yenish and T. Alby III. 2003. Effect of imazamox soil persistence on dryland rotational crops. Weed Technology 17:161-165.

Ball, D. A., F. L. Young, and A. G. Ogg, Jr. 1999b. Selective control of jointed goatgrass with imazamox in herbicide-resistant wheat. Weed Technology 13:77-82.

Barroso, J., J. A. Gourlie, L. K. Lutcher, L. Mingyang, and C. Mallory-Smith. 2018. Identification of glyphosate resistance in *Salsola tragus* in northeastern Oregon. Pest Management Science 74:1089-1093.

Barroso, J., D. Lyon, and T. Prather. 2019. Russian thistle: Management in a wheat-fallow crop rotation. Pacific Northwest Extension Bulletin 492. Oregon State University Extension Service, Corvallis. 10 pages.

Barroso, J., B. D. Maxwell, D. Andujar, C. San Martin, J. Dorado, and C. Fernandez-Quintanilla. 2016. Response of *Sorghum halepense* demographic processes to plant density and rimsulfuron dose. Weed Research 56:304-312.

Barroso, J., J. D. McCallum, and D. S. Long. 2017. Identifying weed infestations with optical data at harvest. Sensors 17:1-17.

Barroso, J., Z. J. Miller, E. A. Lehnhoff, P. Hatfield, and F. D. Menalled. 2015. Impacts of cropping system and management practices on the assembly of weed communities. Weed Research 55:426-435.

Barth, V.P., C.L. Reardon, T. Coffey, A.M. Klein, C. McFarland, D.R. Huggins, and T. S. Sullivan. 2018. Stratification of soil chemical and microbial properties under no-till after liming. Applied Soil Ecology 130: 169-177.

Bayles, B. B., and F. A. Coffman. 1928. Effects of dehulling seed and of date of seeding on germination and smut infection in oats. Journal of the American Society of Agronomy 21:41-51.

Bayles, B. B., and J. F. Martin. 1931. Growth habit and yield in wheat as influenced by time of seeding. Journal of Agricultural Research 42:483-500.

Bechtel, A., and M. Corp. 2001. Flexible Crop-Share Leasing Agreements. Oregon State University Extension Bulletin EM8775. Corvallis, OR.

Belford, R. K., B. Klepper, and R. W. Rickman. 1987. Studies of intact shoot-root systems of field-grown winter wheat. II. Root and shoot developmental patterns as related to nitrogen fertilizer. Agronomy Journal 79:310-319.

Belford, R. K., R. W. Rickman, B. Klepper, and R. R. Allmaras. 1986. Studies of intact shoot-root systems of field-grown winter wheat. I. Sampling Techniques. Agronomy Journal 78:757-760.

Belnap, J., J. H. Kaltenecker, R. Rosenstreter, J. D. Williams, S. Leonard, and D. J. Eldridge. 2001. Biological Soil Crusts: Ecology and Management. Technical Reference 1730-2, USDI, Bureau of Land management, National Science and Technology Center, Information and Communications Group. Denver, CO. 119 pp.

Beutler, L. K. 1963. The potential of oil crops on diverted wheat acres. Oregon Agricultural Experiment Station Circular 616. 4 pages.

Beutler, L. K., and W. H. Foote. 1963. Influence of date of seeding and nitrogen rates on winter wheat varieties in eastern Oregon. Agronomy Journal 55:4-6.

Bista, P., R. Ghimire, S. Machado, and L. Pritchett. 2019. Biochar effects on soil properties and wheat biomass vary with fertility management. Agronomy 9:623. (online at doi:10.3390/agronomy9100623).

Bista, P., S. Machado, R. Ghimire, S. J. Del Grosso, and M. Reyes-Fox. 2016. Simulating soil organic carbon in a wheat-fallow system using the DAYCENT Model. Agronomy Journal 108:2554-2565.

Bista, P., S. Machado, R. Ghimire, G. Yorgey, and D. Wysocki. 2017. Conservation tillage systems. Pages 99-124. In: Advances in Dryland Farming in the Inland Pacific Northwest (G. Yorgey and C. Kruger, editors). Washington State University, Pullman, WA. 614 pages.

Blake, G. R., W. W. Nelson, and R. R. Allmaras. 1976. Persistence of subsoil compaction in a mollisol. Soil Science Society of America Journal 40:943-948.

Blok, V., G. L. Tylka, R. W. Smiley, W. de Jong, and M. Daub. 2018. Resistance breeding. Pages 174-214. In: Cyst Nematodes (R. N. Perry, M. Moens and J. T. Jones, editors). CAB International, Wallingford, UK. 488 pages.

Boawn, L. C., and R. R. Allmaras. 1974a. Mineral concentrations in animal feedstuffs grown in the Columbia Plateau and adjacent valleys. Wash. Agric. Exp. Sta. Res. Bull. 799.

Boawn, L. C., and R. R. Allmaras. 1974b. Zinc status of animal feedstuff grown in the Columbia Basin Plateau and adjacent valleys. Coll. Agric. Res. Ctr. Bull. 805. Washington State Univ., Pullman, WA.

Bockus, W.W., R.L. Bowden, R.M. Hunger, W.L. Morrill, T.D. Murray, and R.W. Smiley (editors). 2010. Compendium of Wheat Diseases and Insects, 3rd edition. APS Press, St. Paul, MN. 171 pages.

Bolton, F. E. 1981. Optimizing the use of water and nitrogen through soil and crop management. Plant and Soil 58:231-247.

Bolton, F. E., and D. E. Booster. 1981. Strip-till planting in dryland cereal production. Transactions of the American Society of Agricultural Engineers 24:59-62.

Bolton, F. E., and D. M. Glenn. 1983. Fallow-cropping systems in the Pacific Northwest. Oregon Agricultural Experiment Station Technical Bulletin 146. 11 pages.

Bolton, F. E., A. P. Appleby, and S. Case. 1992. Re-seeding wheat (*Triticum aestivum*) following preplant treatments of atrazine. Weed Technology 6:996-998.

Boone, M. Y. L., R. W. Rickman, and F. D. Whisler. 1990. Leaf appearance rates of two winter wheat cultivars under high carbon dioxide conditions. Agronomy Journal 82:718-724.

Botha, A. H., J. L. Purchase, and D. E. Wilkins. 1994. Small grain precision planter for dryland experimental plots. Agronomy Journal 86:359-362.

Boukar, I., W. A. Payne, and D. E. Hess. 1996. Dynamics of moisture, nitrogen, and *Striga* infestation on pearl millet transpiration and growth. Agronomy Journal 88:545-549.

Brady, M.V., K. Hedlund, R-G. Cong, L. Hemerik, S. Hotes, S. Machado, L. Mattsson, E. Schulz and I. K. Thomsen. 2015. Valuing supporting soil ecosystem services in agriculture: a natural capital approach. Agronomy Journal 107:1809-1821.

Bressman, E. N. 1931. Varietal Resistance, Physiologic Specialization, and Resistance Studies in Bunt of Wheat. Oregon Agricultural Experiment Station Bulletin 281. Corvallis, OR. 44 pages.

Brown, B. D. and S. E. Petrie. 2005. Irrigated hard winter wheat responses to fall, spring, and late season applied nitrogen. Field Crops Research 96:260-268.

Brown, J., J. B. Davis, D. A. Brown, L. Seip, T. Gosselin, D. Wysocki, and S. Ott. 2005. Registration of 'Athena' Winter Rapeseed. Crop Science 45:800-801.

Brown, W. G., and M. M. Oveson, 1955. Production functions from data over a series of years. Journal of Farm Economics 40:451-457.

Brown, W. G., and M. M. Oveson, 1957. Profitability of fertilizing wheat in Umatilla County. Oregon Agricultural Experiment Station Circular of Information 583. 12 pages.

Brown, W. G., and M. M. Oveson. 1960. Profitability of field crop rotations in Umatilla County. Oregon Agricultural Experiment Station Circular 573. 9 pages.

Brown-Guedira, G. L., C. J. Peterson, S. Leath, P. K. Zwer, J. B. Thomas, W. W. Bockus, B. S. Gill, J. H. Hatchett, and T. S. Cox. 1996. Evaluation of a collection of wild timopheevi wheat for resistance to disease and arthropod pests. Plant Disease 80:928-933.

Bruner, E.A., P. A. Okubara, R. Abi-Ghanem, D. J. Brown, and C. L. Reardon. 2015. Use of pressure cycling technology for cell lysis and recovery of bacterial and fungal communities from soil. Biotechniques 58:171-180.

Camara, K. M., W. A. Payne, and P. E. Rasmussen. 2003. Long-term effects of tillage, nitrogen, and rainfall on wheat yields in the Pacific Northwest. Agronomy Journal 95:828-835.

Castro, A., S. E. Petrie, A. Budde, A. Corey, P. Hayes, J. Kling, and K. Rhinhart. 2008. Variety and N management on grain yield and quality of winter barley. Crop Management 7: (doi:10.1094/CM-2008-1125-01-RS).

Cavigelli, M. A., P. R. Nash, H. T. Gollany, C. Rasmann, R. W. Polumsky, A. N. Le, and A. E. Conklin. 2018. Simulated soil organic carbon changes in Maryland are affected by tillage, climate change, and crop yield. Journal of Environmental Quality 47:588-595.

Chastain, T. G. 1991. High temperature sodium hypochlorite effects on viability of *Tilletia controversa* teliospores and wheat seed. Crop Science 31: 1327-1330.

Chastain, T. G. 1992. Relationship of ergot to Kentucky bluegrass seed production and quality. Journal of Applied Seed Production 10:7-10.

Chastain, T. G., and B. King. 1990. A biochemical method for estimating the viability of teliospores of *Tilletia controversa*. Phytopathology 80:474-476.

Chastain, T. G., and D. F. Grabe. 1988a. Establishment of red fescue seed crops with cereal companion crops. I. Morphological responses. Crop Science 28:308-312.

Chastain, T. G., and D. F. Grabe. 1988b. Establishment of red fescue seed crops with cereal companion crops. II. Seed production and economic implications. Crop Science 28:313-316.

Chastain, T. G., and D. F. Grabe. 1989a. Spring establishment of orchardgrass seed crops with cereal companion crops. Crop Science 29:466-471.

Chastain, T. G., and D. F. Grabe. 1989b. Spring establishment of turf-type tall fescue seed crops with cereal companion crops. Agronomy Journal 81:488-493.

Chastain, T. G., C. M. King, C. J. Garbacik, W. C. Young, and D. J. Wysocki. 2015. Irrigation frequency and seasonal timing effects on perennial ryegrass (*Lolium perenne* L.) seed production. Field Crops Research 180:126-134.

Chastain, T. G., B. L. Klepper, and D. E. Wilkins. 1994. Relationship of wheat seed sprouting severity, planting depth, and seed treatment to emergence and yield. Crop Science 34:508-513.

Chastain, T. G., D. J. Wysocki, and K. J. Ward. 1995a. Seedbed residue and seed size relationships in winter barley. Agronomy Journal 87:517-520.

Chastain, T. G., K. J. Ward, and D. J. Wysocki. 1995b. Stand establishment responses of soft white winter wheat to seed bed residue and seed size. Crop Science 35:213-218.

Chastain, T. G., K. J. Ward, and D. J. Wysocki. 1995c. Winter barley responses to seedbed residue and seed size. Agronomy Journal 87:517-520.

Chatterjee, A., D. S. Long, and F. J. Pierce. 2013. Switchgrass influences on soil biogeochemical processes in the dryland region of the Pacific Northwest. Communications in Soil Science and Plant Analysis 44:2314-2326.

Chatterjee, A., D. S. Long, and F. J. Pierce. 2018. Change in soil organic carbon after five years of continuous winter wheat or switchgrass. Soil Science Society of America Journal 82:332-342.

Chen, C., and W. A Payne. 2001. Measured and modeled unsaturated hydraulic conductivity of a Walla Walla silt loam. Soil Science Society of America Journal 65:1385-1391.

Chen, C., R. J. Roseberg, D. Sugar, and J. S. Selker. 2001. Effect of micro sprinkler irrigation on pear fruit growth and postharvest quality. HortTechnology 11:56-61.

Chen, C., W. A. Payne, R. W. Smiley, and M. A. Stoltz. 2003. Yield and water-use efficiency of eight wheat cultivars planted on seven dates in northeastern Oregon. Agronomy Journal 95:836-843.

Chozinski, A., D. A. Horneck, and D. J. Wysocki. 2013. Eastern Oregon Liming Guide. Oregon State University Extension Publication EM9060. 12 pages.

Clark, J. A., and D. E. Stephens. 1920. Australian Wheat Varieties in the Pacific Coast Area. USDA Bulletin No. 877. US Government Printing Office, Washington, D.C. 25 pages.

Clarke, T. A., M. J. Edwards, A. J. Gates, A. Hall, G. F. White, J. Bradley, C. L. Reardon, L. Shi, A. S. Beliaev, M. J. Marshall, Z. Wang, N. J. Watmough, J. K. Fredrickson, J. M. Zacharara, J. N. Butt, and D. J. Richardson. 2011. Structure of a bacterial cell surface decaheme electron conduit. Proceedings of the National Academy of Sciences USA 108:9384-9389.

Coffman, F. A., T. R. Stanton, B. B. Bayles, G. A. Wiebe, R. W. Smith, and V. F. Tapke. 1931. Inheritance of resistance in oats to *Ustilago levis*. Journal of Agricultural Research 43:1085-1099.

Collins, H. P., L. F. Elliott, and R. I. Papendick. 1990a. Wheat straw decomposition and changes in decomposability during field exposure. Soil Science Society of America Journal 54:1013-1016.

Collins, H. P., L. F. Elliott, R. W. Rickman, D. F. Bezdicek, and R. I. Papendick. 1990b. Decomposition and interactions among wheat residue components. Soil Science Society of America Journal 54:780-785.

Collins, H. P., P. E. Rasmussen, and C. L. Douglas, Jr. 1992. Crop rotation and residue management effects on soil carbon and microbial dynamics. Soil Science Society of America Journal 56:783-788.

Cook, G. H., T. R. Johlke, and R. S. Karow. 1994. Early growth and development of wheat in Northeast Oregon. Oregon State University Extension Service Extension Bulletin EM 8578. Corvallis, OR. 4 pages.

Corp, M. K., D. A. Horneck, D. J. Wysocki, and L. K. Lutcher. 2012. Monitoring soil nutrients in dryland systems using management units. Oregon State University Extension Publication EM8920. 9 pages.

Corp, M., S. Machado, D. Ball, R. Smiley, S. Petrie, M. Siemens, and S. Guy. 2004. Chickpea Production Guide. Oregon State University Extension Publication EM8791-E. 14 pages.

Cruse, R. M., K. N. Potter, and R. R. Allmaras. 1982. Modeling tillage effects on soil temperatures. Pages 133-150. In: Predicting Tillage Effects on Soil Physical Properties and Processes (D. M. Van Doren, editor). ASA Spec. Publication 44. American Society of Agronomy, Madison, WI.

Dababat, A. A., H. Muminjanov, and R. W. Smiley (editors). 2015. Nematodes of Small Grain Cereals: Current Status and Research. FAO, Rome, Italy. 384 pages.

Deepak, K., A. Juneja, W. E. Hohenschuh, J. D. Williams, and G. Murthy. 2012. Chemical composition and bioethanol potential of different plant species found in Pacific Northwest conservation buffers. Journal of Renewable and Sustainable Energy 4, 063114; doi: 10.1063/1.4766889.

Del Grosso, S. J., J. W. White, G. Wilson, B. Vandenberg, D. L. Karlen, R. F. Follett, J. M. F. Johnson, A. J. Franzluebbers, D. W. Archer, H. T. Gollany, M. A. Liebig, J. Ascough, M. Reyes-Fox, L. Pellack, J. Starr, N. Barbour, R. W. Polumsky, M. Gutwein, and D. James. 2013. Introducing the GRACEnet/REAP data contribution, discovery and retrieval system. Journal of Environmental Quality 42:1274-1280.

Del Grosso, S. J., H. T. Gollany, and M. Reyes-Fox. 2016. Simulating soil organic carbon stock changes in agro-ecosystems using CQESTR, DayCent, and IPCC Tier 1 methods. Pages 89-110. In: Synthesis and Modeling of Greenhouse Gas Emissions and Carbon Storage in Agricultural and Forest Systems to Guide Mitigation and Adaptation. (S. Del Grosso, L. Ahuja, and W. Parton, editors). Advances in Agricultural Systems Modeling, Volume 6. American Society of Agronomy, Madison, WI.

Dell, C. J., H. T. Gollany, P. R. Adler, R. H. Skinner, and R. W. Polumsky. 2018. Implications of observed and simulated soil carbon sequestration for management options in corn-based rotations. Journal of Environmental Quality 47:617-624.

Dick, R. P., P. E. Rasmussen, and E. A. Kerle. 1988. Influence of long-term residue management on soil enzyme activities in relation to soil chemical properties in a wheat-fallow system. Biology and Fertility of Soils 6:159-164.

Diebel, P. L., and D. A. Ball. 1999. Economic Analysis of Conservation Farming Systems for Eastern Oregon Wheat Production. Oregon Agricultural Experiment Station Special Report 1004. 56 pages.

Douglas, C. D., Jr., D. J. Wysocki, J. F. Zuzel, R. W. Rickman, and B. L. Klepper. 1990a. Agronomic Zones for the Dryland Pacific Northwest. Pacific Northwest Extension Bulletin PNW 354. 8 pages.

Douglas, C. L., Jr., R. R. Allmaras, P. E. Rasmussen, R. E. Ramig, and N. C. Roager, Jr. 1980. Wheat straw composition and placement effects on decomposition in dryland agriculture of the Pacific Northwest. Soil Science Society of America Journal 44:833-837.

Douglas, C. D., Jr., R. R. Allmaras, and N. C. Roager, Jr. 1984. Silicic acid and oxidizable carbon movement in a Walla Walla silt loam as related to long-term management. Soil Science Society of America Journal 48:156-162.

Douglas, C. L., Jr., P. M. Chevalier, B. Klepper, A. G. Ogg, Jr., and P. E. Rasmussen. 1999. Conservation cropping systems and their management. Pages 73-95. In: Conservation farming in the United States: The methods and accomplishments of the STEEP Program (E. L. Michalson, R. I. Papendick, and J. E. Carlson, editors). CRC Press, Boca Raton, FL.

Douglas, C. L., Jr., K. A. King, and J. F. Zuzel. 1998a. Nitrogen and phosphorus in surface runoff and sediment from a wheat-pea rotation in Northeastern Oregon. Journal of Environmental Quality 27:1170-1177.

Douglas, C. L., Jr., R. E. Ramig, P. E. Rasmussen, and D. E. Wilkins. 1987a. Residue management: Small grains in the Pacific Northwest. Crops and Soils 39:22-24.

Douglas, C. L. Jr., and R. W. Rickman. 1992. Estimating crop residue decomposition from air temperature, initial nitrogen content, and residue placement. Soil Science Society of America Journal 56:272-278.

Douglas, C. L., Jr., R. W. Rickman, B. L. Klepper, J. F. Zuzel, and D. J. Wysocki. 1992. Agroclimatic zones for dryland winter wheat producing areas of Idaho, Washington, and Oregon. Northwest Science 66:26-34.

Douglas, C. L., Jr., R. Rickman, J. Zuzel, and B. Klepper. 1987b. Agronomic zones for the Pacific Northwest. p. 593-594. In (L. F. Elliott, editor) STEEP-Conservation Concepts and Accomplishments. Washington State Univ., Pullman, WA

Douglas, C. L., Jr., R. W. Rickman, J. F. Zuzel, and B. L. Klepper. 1988. Criteria for delineation of agronomic zones in the Pacific Northwest. Journal of Soil and Water Conservation 43:415-418.

Douglas, C. L., Jr., T. R. Toll, B. L. Klepper, and D. E. Wilkins. 1990b. Identifying individual plants or plant parts during shoot and root evaluations. Agronomy Journal 82:1169-1170.

Douglas, C. L., Jr., P. E. Rasmussen, and R. R. Allmaras. 1989. Cutting height, yield level, and equipment modification effects on residue distribution by combines. Transactions of the American Society of Agricultural Engineers 32:1258-1262.

Douglas, C. L. Jr., P. E. Rasmussen, and R. R. Allmaras. 1992. Nutrient distribution following wheat residue dispersal by combines. Soil Science Society of America Journal 56:1171-1177.

Douglas, C. L., Jr., P. E. Rasmussen, R. R. Allmaras, and L. L. Baarstad. 1987c. Residue distribution behind combines. p. 557-559. In (L.F. Elliott, editor) STEEP-Soil Conservation Concepts and Accomplishments. Washington State Univ., Pullman, WA

Douglas, C. L., Jr., P. E. Rasmussen, H. P. Collins, and S. L. Albrecht. 1998b. Nitrogen mineralization across a climosequence in the Pacific Northwest. Soil Biology and Biochemistry 30:1765-1772.

Douglas, C. L., Jr., D. E. Wilkins, and D. B. Churchill. 1994. Tillage, seed size, and seed density effects on performance of soft white winter wheat. Agronomy Journal 86:707-711.

Duff, B., P. E. Rasmussen, and R. W. Smiley. 1995. Wheat-fallow systems in the semi-arid regions of Pacific NW America. Pages 85-111. In: Agricultural Sustainability: Economic, Environmental and Statistical Considerations (V. Barnett, R. Payne and R. Steiner, editors). John Wiley & Sons, London. 266 pages.

DuVal, A., T. G. Chastain, C. J. Garbacik, and D. J. Wysocki. 2017. Nitrogen affects seed production characteristics in yellow mustard. Agronomy Journal 109:995-1004.

Eitel, J. H., D. S. Long, P. E. Gessler, and E. R. Hunt, Jr. 2008. Combined spectral index to improve ground-based estimates of nitrogen status in dryland wheat. Agronomy Journal 100:1694-1702.

Eitel, J. H., D. S. Long, P. E. Gessler, E. R. Hunt, Jr., and D. J. Brown. 2009. Sensitivity of ground-based remote sensing estimates of wheat chlorophyll content to variation in soil reflectance. Soil Science Society of America Journal 73:1715-1723.

Eitel, J. H., D. S. Long, P. E. Gessler, and A. S. Smith. 2007. Using in-situ measurements to evaluate new RapidEye™ satellite series for prediction of wheat nitrogen status. International Journal of Remote Sensing 28:4183-4190.

Eitel, J. U. H., L. A. Vierling, D. S. Long, and E. R. Hunt. 2011. Early season remote sensing of wheat nitrogen status using a green scanning laser. Agricultural and Forest Meteorology 151:1338-1345.

Elliott, L. F., D. E. Stott, C. L. Douglas, R. I. Papendick, G. S. Campbell, and H. Collins. 1999. Residue management issues for conservation tillage systems. Pages 57-72. In: Conservation farming in the United States: The methods and accomplishments of the STEEP Program (E. L. Michalson, R. I. Papendick, and J. E. Carlson, editors). CRC Press, Boca Raton, FL.

Elliott, L. F., H. F. Stroo, R. I. Papendick, C. L. Douglas, Jr., G. S. Campbell, and D. E. Scott. 1987. Decomposition of surface managed crop residues. Pages 81-91. In: STEEP-Soil Conservation Concepts and Accomplishments (L.F. Elliott, editor). Washington State Univ., Pullman, WA

Elsidaig, A. A., and P. K. Zwer. 1993. Genes for host resistance to Russian wheat aphid in PI294994 wheat. Crop Science 33:998-1001.

Engle, C. F., and C. B. Harston. 1975. Erosion and Sedimentation in the Loessial Region of Washington, Idaho, and Oregon. Council for Agricultural Science and Technology Report No. 42. Washington, D.C. 15 pages. (authors included 21 other task force members, including Raymond R. Allmaras and Robert E. Ramig, at Pendleton).

Erbach, D. C., J. E. Morrison, and D. E. Wilkins. 1983. Equipment modification and innovation for conservation tillage. Journal of Soil and Water Conservation 38:182-185.

Ferguson, B. T., T. G. Chastain, C. J. Garbacik, B. T. Chastain, and D. J. Wysocki. 2016. Spring nitrogen and cultivar affect seed production in winter canola. Agronomy Journal 108:1124-1131.

Fisher, G., K. Pike, R. W. Rickman, and D. Maxwell. 1981. The Hessian fly in Oregon. Oregon Agricultural Experiment Station Circular of Information 1093.

Florell, V. H., and J. F. Martin. 1936. Inheritance of complementary dwarfing factors in wheat. Journal of Agricultural Research 53:151-160.

Foote, W. H., C. R. Rohde, M. J. Johnson, W. E. Hall, A. E. Gross, and E. N. Hoffman. 1961. Cereal Variety Recommendations for Oregon. Oregon Agricultural Experiment Station Circular of Information 575.

Fuentes, J. P., D. F. Bezdicek, M. Flury, S. Albrecht, and J. L. Smith. 2006. Microbial activity affected by lime in a long term no-till soil. Soil and Tillage Research 88:123-131.

George, D. W. 1964. Chemical control of stripe rust on Omar wheat. Plant Disease Reporter 48:162-166.

George, D. W. 1967. High temperature seed dormancy in wheat (*Triticum aestivum* L.). Crop Science 7:249-253.

George, G. O. 1980. Monitoring Terrace Control of Water Pollution from Soil Erosion and Sediment in the Columbia Basin Counties of Oregon: October 1978 to April 1979. Oregon Agricultural Experiment Station Special Report 595. 7 pages.

George, G. O. 1981. Best Management Practices and Water Quality Demonstration and Evaluation Project: Five-county North Central Area. Oregon Agricultural Experiment Station Special Report 606. 14 pages.

George, G. O. 1982. Best Management Practices and Water Quality Demonstration and Evaluation Project: Five-county North Central Area – October 1977 to April 1981. Oregon Agricultural Experiment Station Special Report 646. 72 pages.

Gesch, R., T. Isbell, B. Allen, D. Archer, J. Brown, J. Hatfield, J. Kiniry, D. Long, and M. Vigil. 2015. Comparison of several *Brassica* species in the northcentral U.S. for potential jet fuel feedstock. Industrial Crops and Products 75:2-7.

Gesch, R. W., D. S. Long, D. Palmquist, B. L. Allen, D. W. Archer, J. Brown, J. B. Davis, J. L. Hatfield, J. D. Jabro, J. R. Kiniry, M. F. Vigil, E. A. Oblath, and T. A. Isbell. 2019. Agronomic performance of Brassicaceae oilseeds in multiple environments across the western USA. Bioenergy Research. 12:509-523.

Ghimire, R., P. Bista, and S. Machado. 2019. Long-term management effects and temperature sensitivity of soil organic carbon in grassland and agricultural soils. Scientific Reports 9:12151. Online at https://doi.org/10.1038/s41598-019-48237-7.

Ghimire, R., S. Machado, and P. Bista. 2017. Soil pH, soil organic matter, and crop yield in wheat-fallow systems. Agronomy Journal 109:1-12.

Ghimire, R., S. Machado, and P. Bista. 2018. Decline in soil organic carbon and nitrogen limits yield in wheat-fallow systems. Plant and Soil 422:423–435.

Ghirmire, R., S. Machado, and K. Rhinhart. 2015. Long-term crop residue and nitrogen management effects on soil profile carbon and nitrogen in wheat-fallow systems. Agronomy Journal 107:2230-2240.

Gohlke, T. M., and D. J. Wysocki. 1990. Nutrient and Pesticide Management Guides. Oregon Soil Conservation Service Field Office Technical Guide.

Gollany, H. T. 2016. CQESTR simulation of dryland agroecosystem soil organic carbon changes under climate change scenarios. Pages 59-87. In: Synthesis and Modeling of Greenhouse Gas Emissions and Carbon Storage in Agricultural and Forest Systems to Guide Mitigation and Adaptation (S. Del Grosso, L. Ahuja, and W. Parton, editors). Advances in Agricultural Systems Modeling, Volume 6. American Society of Agronomy, Madison, WI. 317 pages.

Gollany, H. T., R. R. Allmaras, S. L. Albrecht, S. M. Copeland, and C. L. Douglas, Jr. 2006. Incorporated source carbon and nitrogen fertilizer influence on sequestered carbon and soluble silica in a Pacific Northwest mollisol. Soil Science 171:585-597.

Gollany, H.T., R. R. Allmaras, S. M. Copeland, S. L. Albrecht, and C. L. Douglas, Jr. 2005. Tillage and nitrogen fertilizer influence on carbon and soluble silica relations in a Pacific Northwest mollisol. Soil Science Society of America Journal 69:1102-1109.

Gollany, H. T., and A. A. Elnaggar. 2017. Simulating soil organic carbon changes across toposequences under dryland agriculture using CQESTR. Ecological Modelling 355:97-104.

Gollany, H. T., R. F. Follett, and Y. Liang. 2012a. CQESTR simulations of soil organic carbon dynamics. Pages 271-292. In: Managing Agricultural Greenhouse Gases: Coordinated Agricultural Research Through GRACEnet to Address our Changing Climate (M. A. Liebig, A. J. Franzluebbers, and R. F. Follett, editors). Academic Press, San Diego, CA.

Gollany, H. T., A. Fortuna, M. Samuel, F. L. Young, W. Pan, and M. Pecharko. 2012b. Estimating soil organic carbon accretion vs. sequestration using chemical and physical fractionation and the CQESTR model. Soil Science Society of America Journal 76: 618 –629.

Gollany, H. T., J.-A. E. Molina, C. E. Clapp, R. R. Allmaras, M. F. Layese, J. M. Baker, and H. H. Cheng. 2004. Nitrogen leaching and denitrification in continuous corn as related to residue management and nitrogen fertilization. Environmental Management 33:S289-298.

Gollany, H. T., P. R. Nash, J. M. Johnson, and N. W. Barbour. 2019. Predicted annual biomass input to maintain soil organic carbon under contrasting management. Agronomy Journal 111:1-11.

Gollany, H. T., J. M. Novak, Y. Liang, S. L. Albrecht, R. W. Rickman, R. F. Follett, W. W. Wilhelm, and P. G. Hunt. 2010. Simulating soil organic carbon dynamics with residue removal using the CQESTR model. Soil Science Society of America Journal 74:372-383.

Gollany, H. T., and R. W. Polumsky. 2018. Simulating soil organic carbon responses to cropping intensity, tillage, and climate change in Pacific Northwest dryland. Journal of Environmental Quality 47:625-634.

Gollany, H. T., R. W. Rickman, Y. Liang, S. L. Albrecht, S. Machado, and S. Kang. 2011. Predicting agricultural management influence on long-term soil organic carbon dynamics: Implications for biofuel production. Agronomy Journal 103:234–246.

Gollany, H.T., M.A. Schmitt, P.R. Bloom, G.W. Randall and P.R. Carter. 2003. Extractable phosphorus following soil amendment with manure from swine fed low-phytate corn. Soil Science 168:606- 616.

Gollany, H. T., B. D. Titus, D. A. Scott, H. Asbjornsen, S. C. Resh, R. A. Chimner, D. J. Kaczmarek, L. F. C. Leite, A. C. C. Ferreira, K. Rod, J. Hilbert, M. V. Galdos, and M. E. Cisz. 2015. Biogeochemical research priorities for sustainable biofuel and bioenergy feedstock production in the Pan-Americas. Environmental Management 56:1330-1355.

Gollany, H. T., and R. T. Venterea. 2018. Measurements and models to identify agroecosystem practices that enhance soil organic carbon under changing climate. Journal of Environmental Quality 47:579-587.

Goss, R. L., and R. W. Smiley. 1987. Diseases of turfgrasses in relation to management. New Zealand Turf Management Journal 1:17-20.

Graebner, R. C., C. R. Brown, R. E. Ingham, C. H. Hagerty, H. Mojtahedi, R. A. Quick, L. L. Hamlin, N. Wade, J. B. Bamberg, and V. Sathuvalli. 2018. Resistance to *Meloidogyne chitwoodi* identified in wild potatoes. *Journal of American Potato Research* 95:679-686.

Griffin, T. S., C. W. Honeycutt, S. L. Albrecht, K. R. Sistani, H. A. Torbert III, B. J. Wienhold, B. L. Woodbury, R. K. Hubbard, and J. M. Powell. 2008. Nationally coordinated evaluation of soil nitrogen mineralization rate using a standardized aerobic incubation protocol. Communications in Soil Science and Plant Analysis 39:257-268

Grunes, D. L., R. W. Rickman, and B. Klepper. 1987. Plant roots in relation to soil fertility. Pages 245-258. In: Future Developments in Soil Fertility and Plant Nutrition (T. C. Tucker, editor). Soil Science Society of America, Madison, WI.

Gupta, S.C., W.E. Larson, and R.R. Allmaras. 1984. Predicting soil temperatures under different tillage-surface residue conditions from daily maximum air temperatures. Soil Science Society of America Journal 48:223-332.

Guy, S. O., D. J. Wysocki, W. F. Schillinger, T. G. Chastain, R. S. Karow, K. Garland-Campbell, and I. C. Burke. 2014. Camelina: Adaptation and performance of genotypes. Field Crops Research 155:224-232.

Gwenzi, W., N. Chaukura, F.N.D. Mukome, S. Machado, B. Nyamasoka. 2015. Biochar production and applications in sub-Saharan Africa: Opportunities, constraints, risks and uncertainties. Journal of Environmental Management 150:250-261.

Ghimire, R., S. Machado, and P. Bista. 2017. Soil pH, soil organic matter, and crop yields in winter wheat–summer fallow systems. Agronomy Journal 109:706-717.

Haddadi, F., A. Mokabli, and R. W. Smiley. 2013. Characterisation of virulence reactions for *Heterodera avenae* populations from two localities in Algeria. Phytoparasitica 41:449-456.

Hafenrichter, A. L., J. L. Schwendiman, H. L. Harris, R. S. MacLauchlan, and H. W. Miller. 1968. Grasses and Legumes for Soil Conservation in the Pacific Northwest and Great Basin States. Agriculture Handbook 339. USDA Soil Conservation Service, Washington, D.C. 69 pages.

Hagerty, C. H., N. P. Anderson, and C. C. Mundt. 2016. Temporal dynamics and spatial variation of *Zymoseptoria tritici* fungicide resistance: A hierarchical survey of commercial winter wheat fields in the Willamette Valley, Oregon. Phytopathology 107:345-352.

Hagerty, C. H., K. C. Fickas, and D. J. Wysocki. 2019a. Agronomic Zones of the Dryland Pacific Northwest. PNW Extension Publication 354. Corvallis, Oregon. 6 pages.

Hagerty, C. H., R. C. Graebner, K. S. Sackett, and C. C. Mundt. 2017. Variable competitive effects of fungicide resistance in field experiments with a plant pathogenic fungus. Ecological Applications 27:1305–1316.

Hagerty, C. H., D. K. Kroese, C. C. Mundt, A. F. Heesacker, and R. S. Zemetra. 2019b. Eyespot of Wheat: How to Identify and Control this Common Fungal Disease. Oregon State University Extension Memo EM 9232. Corvallis, Oregon. 6 pages.

Hagerty, C. H., and R. Smiley. 2017. Field Guide for Diagnosing Common Wheat Maladies of the Pacific Northwest. PNW Extension Publication 698. Corvallis, Oregon. 11 pages.

Hajihassani, A., R. W. Smiley, and F. J. Afshar. 2013. Effects of co-inoculations with *Pratylenchus thornei* and *Fusarium culmorum* on growth and yield of winter wheat. Plant Disease 97:1470-1477.

Hall, W. E. 1957. Report of Chrysanthemums Tested at the Sherman Branch Experiment Station. An Unpublished Paper. 6 pages.

Hall, W. E. 1959a. Examples of Accomplishments and Projects at the Sherman Branch Experiment Station, Moro, Oregon: 1909-1959. An Unpublished Station Summary. 7 pages.

Hall, W. E. 1959b. History of Wheat Varieties in Sherman County. An Unpublished Paper. 5 pages.

Hall, W. E. 1961. Fifty Years of Research at the Sherman Branch Experiment Station. Oregon Agricultural Experiment Station Miscellaneous Paper 104. 16 pages.

Hall, W. E. 1997. My Life in Moro with the Sherman Experiment Station. Sherman County: For the Record 15(1):17-29. Sherman County Historical Society, Moro, Oregon.

Hall, W. E., and W. H. Foote. 1957. Columbia, A New Hard Red Winter Wheat. Oregon Agricultural Experiment Station Circular of Information 564. 4 pages.

Halvorson, J. J., H. T. Gollany, A. C. Kennedy, A. E. Hagerman, J. M. Gonzalez, and S. B. Wuest. 2012. Sorption of tannin and related phenolic compounds and effects on extraction of soluble-N in soil amended with several carbon sources. Agriculture 2:52-72.

Hane, D. C., and F. V. Pumphrey. 1984a. Yield-evapotranspiration relationships and seasonal crop coefficients for frequently irrigated potatoes. American Potato Journal 61:661-668.

Hane, D. C., and F. V. Pumphrey. 1984b. Crop water use curves for irrigation scheduling. Oregon Agricultural Experiment Station Special Report 706. 7 pages.

Hansen N. C., B. L. Allen, S. Anapalli, R. E. Blackshaw, D. J. Lyon, and S. Machado. 2017. Dryland agriculture in North America. Pages 415-441. In: Innovations in Dryland Agriculture (M. Farooq and K. H. M. Siddique, editors). Cham, Springer.

Hanson, C. L, J. F. Zuzel, and R. P. Morris. 1983. Winter precipitation measured by heated tipping bucket rain gages. Transactions of the American Society of Agricultural Engineers 26:1479-1480.

Hanson, D. E., D. A. Ball, and C. A. Mallory-Smith. 2002. Herbicide resistance in jointed goatgrass (*Aegilops cylindrica*): Simulated responses to agronomic practices. Weed Technology 16:156-163.

Harris, L. E., and G. A. Mitchell. 1944. Control of Wild Morning Glory or Bindweed by Cultural Methods. Oregon State College Agri. Exp. Station Circular of Information 336. 14 pages.

Healy, F.G., C. Latorre, S.L. Albrecht, P.M. Reddy and K.T. Shanmugam. 2003. Altered kinetic properties of tyrosine-183 to cysteine mutation in glutamine synthetase of *Anabaena variabilis* strain SA1 is responsible for excretion of ammonium ion produced by nitrogenase. Current Microbiology 46:423-431.

Hickman, J., J. Jacobsen, D. Lyon, D. Wysocki et al. 1994. Best management practices for wheat - a guide to profitable and environmentally sound production (S. Watson, editor). National Association of Wheat Growers Foundation, Washington, D.C. 119 pages.

Hill, D. D., D. E. Stephens, D. E. Richards, R. E. Hutchison, and J. F. Martin. 1938. Barley Production in Oregon. Agricultural Experiment Station Bulletin 355, Oregon State College, Corvallis. 34 pages.

Honeycutt, C.W., T.S. Griffin, B.J. Wienhold, B. Eghball, S.L. Albrecht, J.M. Powell, B.L. Woodbury, K.R. Sistani, R.K. Hubbard, H.A. Torbert, R.A. Eigenberg, R.J. Wright, and M.D. Jawson. 2005. Protocols for nationally coordinated laboratory and field research on manure nitrogen mineralization. Communications in Soil Science and Plant Analysis 36:2807-2822.

Horneck, D. A., J. M. Hart, M. D. Flowers, L. K. Lutcher, D. J. Wysocki, M. K. Corp, and M. Bohle. 2015. Irrigated soft white wheat (Eastern Oregon) nutrient management guide. Oregon State University Extension Publication EM 9015. Corvallis, OR. 10 pages.

Horneck, D. A., D. J. Wysocki, B. Hopkins, J. Hart, and R. Stevens. 2006. Acidifying soil for crop production east of the Cascades. Oregon State University Extension Publication EM 8917-E. Corvallis, OR.

Horneck, D. A., D. J. Wysocki, B. G. Hopkins, J. M. Hart, and R. G. Stevens. 2013. Acidifying soil for crop production: Inland Pacific Northwest. Pacific Northwest Extension Bulletin PNW 599. Corvallis, OR. 15 pages.

Horner, G. M., M. M. Oveson, G. O. Baker, and W. W. Pawson. 1960. Effect of cropping practices on yield, soil organic matter, and erosion in the Pacific Northwest wheat region. Washington, Idaho and Oregon Agricultural Experiment Station and USDA-ARS Cooperative Bulletin No. 1. Pullman, Washington. 25 pages.

Horning, T. R., and M. M. Oveson, 1962a. Cloddy and conventional seedbeds for wheat production in the Northwest. Agronomy Journal 54:229-232.

Horning, T. R., and M. M. Oveson. 1962b. Stubble Mulching in the Northwest. USDA Agriculture Information Bulletin No. 253. US Government Printing Office, Washington, D.C., and Oregon Agricultural Experiment Station, Corvallis, Oregon. 28 pages.

Huettig, K. D., W. C. Young III, D. J. Wysocki, T. G. Chastain, and C. J. Garbacik. 2013. Spring irrigation of tall fescue for seed production. Field Crops Research 144:297-304.

Hunter, B. 1918. Increasing the Production of Wheat on Washington Dry Farms by Better Cultural Methods. State College of Washington Extension Bulletin 40. 16 pages.

Hunter, B. 1927. Dry Farming Methods and Practices in Wheat Growing in the Columbia and Snake River Basins. USDA Farmers' Bulletin No. 1545. US Government Printing Office, Washington, D.C. 22 pages.

Hunter, A. S., L. A. Alban, C. J. Gerard, W. E. Hall, and H. E. Cushman. 1961a. Wheat fertilization experiments in the Columbia Basin, 1953-57. Oregon Agricultural Experiment Station Circular of Information 607. 22 p.

Hunter, A. S., L. A. Alban, C. J. Gerard, W. E. Hall, H. E. Cushman, and R. G. Petersen. 1957a. Fertilizer needs of wheat in the Columbia Basin dryland wheat area of Oregon. Oregon Agricultural Experiment Station Technical Bulletin 57. 60 pages.

Hunter, A. S., C. J. Gerard, and H. M. Waddoups. 1956. Pastry wheat quality and yield improved by nitrogen. Journal of Soil and Water Conservation 11:190-191.

Hunter, A. S., C. J. Gerard, H. M. Waddoups, W. E. Hall, H. E. Cushman, and L. A. Alban. 1958a. The effect of nitrogen fertilizers on the relationship between increases in yields and protein content of pastry-type wheats. Agronomy Journal 50:311-314.

Hunter, A. S., C. J. Gerard, M. Waddoups, W. E. Hall, H. E. Cushman, and L. A. Alban. 1957b. Wheat fertilization experiments in the Columbia Basin. Oregon Agricultural Experiment Station Circular of Information 570. 24 pages.

Hunter, A. S., C. J. Gerard, M. Waddoups, W. E. Hall, H. E. Cushman, and L. A. Alban. 1961b. Fertilizer needs of wheat in the Columbia Basin dryland wheat area of Oregon. Oregon Agricultural Experiment Station Technical Bulletin 57.

Hunter, A. S., W. E. Hall, and C. J. Gerard. 1958b. Substantial residual effects of nitrogen observed on summer fallow wheatland in Oregon. Journal of Soil and Water Conservation 13:75-76.

Hyde, G. M, C. E. Johnson, J. B. Simpson, and D. M. Payton. 1979. Grain drill design concepts for Pacific Northwest conservation farming. American Society of Agricultural Engineers Paper No. 79-1525.

Hyde, G. M., D. E. Wilkins, K. Saxton, J. Hammel, G. Swanson, R. Hermanson, E. Dowding, J. Simpson, and C. Peterson. 1987. Reduced tillage seeding equipment development. Pages 41-56. In: STEEP-Soil Conservation Concepts and Accomplishments (L. F. Elliott, editor). Washington State Univ., Pullman, WA.

Inostroza, L., A. del Pozo, I. Matus, D. Castillo, P. Hayes, S. Machado, and A. Corey. 2009. Association mapping of plant height, yield, and yield stability in recombinant chromosome substitution lines (RCSLs) using *Hordeum vulgare* subsp. *spontaneum* as a source of donor alleles in a *Hordeum vulgare* subsp. *vulgare* background. Molecular Breeding 23:365-376.

Istok, J. D., J. F. Zuzel, L. Boersma, D. K. McCool and M. Molnau. 1987. Advances in our ability to predict rates of runoff and erosion using historical climatic data. Pages 205-224. In: STEEP-Soil Conservation Concepts and Accomplishments (L. F. Elliott, editor). Washington State Univ., Pullman, WA.

Jackman, E. R., D. E. Stephens, and D. E. Richards. 1936. Crested Wheat Grass in Eastern Oregon. Extension Bulletin 494. Oregon State System of Higher Education and Federal Cooperative Extension Service, Corvallis. 40 pages.

Jardine, J. T. 1922. The Rise, Development, and Value of the Agricultural Experiment Station. Agricultural Experiment Station Circular 26, Oregon Agricultural College, Corvallis. 38 pages.

Jemmett, E. D., D. C. Thill, T. A. Rauch, D. A. Ball, S. M. Frost, L. H. Bennett, J. P. Yenish, and R. J. Rood. 2008. Rattail fescue (*Vulpia myuros*) control in chemical-fallow cropping systems. Weed Technology 22:435-441.

Johnson, C. E., R. D. Bowen, W. Buchele, and H. Wittmus. 1978a. Soil dynamics in undergraduate education. American Society of Agricultural Engineers Paper No. 78-1033.

Johnson, C. E., E. A. Dowding, and P. K. Turnquist. 1977a. A power driven hay core sampler. Transactions of the American Society of Agricultural Engineers 20:638-639.

Johnson, C. E., E. A. Dowding, and P. K. Turnquist. 1977b. A weighing system for field use. Transactions of the American Society of Agricultural Engineers 20:621-622.

Johnson, C. E., L. L. Jensen, R. L. Schafer, and A. C. Bailey. 1978b. Some soil-tool analogs. American Society of Agricultural Engineers Paper No. 78-1037.

Johnson, C. E., and W. Voorhees. 1979. A force dynamometer for three-point hitches. Transactions of the American Society of Agricultural Engineers 22:226-228, 232.

Jones, J. S., and G. A. Mitchell. 1926. The cause and control of yellow berry in Turkey wheat grown under dry-farming conditions. Journal of Agricultural Research 33:281-292.

Jones, J. S., and W. W. Yates. 1924. The problem of soil organic matter and nitrogen in dry-land agriculture. Agronomy Journal 16:721-731.

Juneja, A., D. Kumar, J. D. Williams, D. J. Wysocki, and G. S. Murthy. 2011. Potential for ethanol production from conservation reserve program lands in Oregon. Journal of Renewable and Sustainable Energy 3:063102. doi 10.1063/1.3658399.

Kamuru, F., S. L. Albrecht, J. T. Baker, L. H. Allen, Jr., and K. T. Shanmugam. 1994. Growth responses of paddy rice to an ammonia-excreting mutant cyanobacterium at elevated CO2 concentration. Applied Soil Ecology 1:199-206.

Kamuru, F., S. L. Albrecht, L. H. Allen, Jr., and K. T. Shanmugam. 1997. Growth and accumulation of 15N in rice inoculated with the parent and a nitrogenase-derepressed mutant strain of *Anabaena variabilis*. Applied Soil Ecology 5:189-195.

Kamuru, F., S. L. Albrecht, L. H. Allen, Jr., and K. T. Shanmugam. 1998. Dry matter and nitrogen accumulation in rice inoculated with a nitrogenase derepressed mutant of *Anabaena variabilis*. Agronomy Journal 90:529- 535.

Kandel, S. L., R. W. Smiley, K. Garland-Campbell, A. A. Elling, J. Abatzoglou, D. Huggins, R. Rupp, and T. C. Paulitz. 2013. A survey of root lesion nematodes (*Pratylenchus* spp.) and their relationship with climatic factors in dryland wheat production areas of eastern Washington. Plant Disease 97:1448-1456.

Kane, R. T., R. W. Smiley, and M. E. Sorrells. 1987. Relative pathogenicity of selected *Fusarium* species and *Microdochium bolleyi* to winter wheat in New York. Plant Disease 71:177-181.

Karow, R. S., M. Barnum, M. Bohle, R. Dovel, and P. K. Zwer. 1993a. Spring wheat and triticale cultivars for Oregon. Oregon Extension Service Crop Science Report SR78. Corvallis, OR.

Karow, R. S., E. L. Klepper, R. W. Rickman, and T. R. Toll. 1993b. Early growth and development of cereals. A Companion to the Videotape, "Early Growth and Development of Cereals". Oregon State University Extension Publication EM8542. Corvallis, OR. 4 pages.

Karow, R. S., W. E. Kronstad, M. F. Kolding, B. D. Brown, and P. K. Zwer. 1992a. New winter wheat varieties, MacVicar -- a soft, white, winter wheat. Oregon State University Extension Service Publication EM8510. Corvallis, OR.

Karow, R. S., W. E. Kronstad, M. F. Kolding, and M. Verhoeven. 1992b. New winter feed barleys, Gwen -- a six-row, winter feed barley. Oregon State University Extension Service Publication EM8511. Corvallis, OR.

Karow, R. S., W. E. Kronstad, M. F. Kolding, and P. K. Zwer. 1992c. New winter wheat varieties, Hoff -- a hard, red, winter wheat. Oregon State University Extension Service Publication EM8512. Corvallis, OR.

Karow, R. S., W. E. Kronstad, M. F. Kolding, and P. K. Zwer. 1992d. New winter wheat varieties, Gene -- a soft, white, winter wheat. Oregon State University Extension Service Publication EM8508. Corvallis, OR.

Karow, R., and F. V. Pumphrey. 1986a. Growing rapeseed in Oregon's drylands. Dept. of Crop Science Ext/CRS 63. Oregon State Univ.

Karow, R., and F. V. Pumphrey. 1986b. Potentials and problems of rapeseed production in Oregon. Dept. of Crop Sci. Ext/CRS 64, Oregon State Univ.

Karow, R. S., and P. K. Zwer. 1993. New winter wheat varieties, Rohde--a winter club wheat. Oregon State University Extension Publication EM 8545. Corvallis, OR.

Karow, R. S., P. K. Zwer, M. Barnum, M. Bohle, M. F. Kolding, and W. E. Kronstad. 1993c. Winter wheat varieties for 1993. Oregon State University Extension Service Publication SR775. Corvallis, OR.

Kendall, J., D. Long, H. Collins, F. Pierce, A. Chatterjee, J. Smith, and S. Young, S. 2015. Soil carbon dynamics during the transition to cellulosic ethanol feedstock production. Soil Science Society of America Journal 79:272-281.

Kendrick, E. L., R. J. Metzger, and C. R. Rohde. 1964. Overwintering of race T-18 of *Tilletia caries*. Plant Disease Reporter 48:379-380.

Kennedy, A. C., L. F. Elliott, F. L. Young, and C. L. Douglas, Jr. 1991. Rhizobacteria suppressive to the weed downy brome. Soil Science Society of America Journal 55:722-727.

Kettel, K., B. Tuck, W. A. Payne, C. Chen, S. Machado, and R. Karow. 2013. Dryland cropping systems: Narrow-leaf lupin. Oregon State University Extension Service Publication EM8834. Corvallis, OR. 11 pages.

Kirby, E., W. Pan, D. Huggins, K. Painter, and P. Bista. 2017. Rational diversification and intensification. Pages 163-236. In: Advances in Dryland Farming in the Inland Pacific Northwest (G. Yorgey and C. Kruger, editors). Washington State Universtiy, Pullman, WA. 614 pages.

Klepper, B. 1983. Managing root systems for efficient water use: Axial resistances to flow in root systems - anatomical considerations. Pages 115-125. In: Limitations to Efficient Water Use in Crop Production (H. M. Taylor, W. R. Jordan, and T. R. Sinclair, editors). American Society of Agronomy, Madison, WI.

Klepper, B. 1984. Response of the wheat plant to non-animal stresses. Pages 235-243. In: Proceedings of National Wheat Pasture Symposium (G. W. Horn, editor). Oklahoma Agricultural Experiment Station Miscellaneous Publication 115, Stillwater, OK.

Klepper, B. 1986. Long-term career goals for women in agriculture. Journal of Agronomic Education 15:29-33.

Klepper, B. 1987. Origin, branching, and distribution of root systems. Pages 103-124. In: Root Development and Function (P. J. Gregory, J. V. Lake, and D. A. Rose, editors). Cambridge University Press.

Klepper, B. 1988. Water Conservation and Use. Rapporteur's Report. Page 170. In: Challenges in Dryland Agriculture - A Global Perspective (P. W. Unger, T. V. Sneed, W. R. Jordan, and R. W. Jensen, editors). Proceedings of the International Conference on Dryland Farming. Texas Agricultural Experiment Station, Amarillo, TX. 965 pages.

Klepper, B. 1990. Root growth and water uptake. Pages 281-322. In: Irrigation of Agricultural Lands (B. A. Stewart and D. R. Nielsen, editors). American Society of Agronomy, Madison, WI.

Klepper, B. 1991a. Crop root system response to irrigation. Irrigation Science 12:105-108.

Klepper, B. 1991b. Root-shoot relationships. Pages 265-286. In: Plant Roots: The Hidden Half (Y. Waisel, U. Kafkafi, and A. Eshel, editors). Marcel Dekker, NY.

Klepper, B. 1992a. Development and growth of crop root systems. Advances in Soil Science 19:1-25.

Klepper, B. 1992b. Roots - Past, present, and future. Pages 7-18. In: Roots of Plant Nutrition (H. F. Reetz, Jr., editor). Proceedings of a Conference of the Potash and Phosphate Institute at Champaign, IL., Atlanta, GA.

Klepper, B., R. K. Belford, and R. W. Rickman. 1984. Root and shoot development in winter wheat. Agronomy Journal 76:117-122.

Klepper, B., A. B. Frank, A. Bauer, and J. A. Morgan. 1985. Physiological and phenological research in support of wheat yield modeling. Pages 134-150. In: ARS Wheat Yield Project (W. O. Willis, editor). USDA, ARS ARS-38.

Klepper, B. and T. C. Kaspar. 1994. Rhizotrons: Their development and use in agricultural research. Agronomy Journal 86:745-753.

Klepper, B., P. E. Rasmussen, and R. W. Rickman. 1982a. Fertilizer placement for cereal root access. Journal of Soil and Water Conservation 38:250-252.

Klepper, B., and R. W. Rickman. 1987. Understanding wheat growth as a management tool. Pages 13-23. In: Proceedings of the Central Great Plains Profitable Wheat Management Workshop (J. L. Havlin, editor). Kansas State University, Manhattan, KS.

Klepper, B., and R. W. Rickman. 1988a. Cereal root systems as related to management in dryland agriculture. Pages 507-509. In: Challenges in Dryland Agriculture - A Global Perspective (P. W. Unger, T. V. Sneed, W. R. Jordan, and R. W. Jensen, editors). Proceedings of the International Conference on Dryland Farming. Texas Agricultural Experiment Station, Amarillo, TX. 965 pages.

Klepper, B., and R. W. Rickman. 1988b. Plant response to conservation tillage. Pages 227-238. In: Land Degradation and Conservation Tillage (J. T. Harapiak, editor). Proceedings of a Symposium at the Institute of Canada Annual Meeting. Canadian Society of Soil Sciences, Calgary, Alberta, Canada.

Klepper, B., and R. W. Rickman. 1990. Modelling crop root growth and function. Advances in Agronomy 44:113-132.

Klepper, B., and R. W. Rickman. 1991. Predicting root development of crop plants. Pages 85-99. In: Predicting Crop Phenology (T. Hodges, editor). CRC Press, Boca Raton, FL.

Klepper, B., R. W. Rickman, and R. K. Belford. 1983a. Leaf and tiller identification on wheat plants. Crop Science 23: 1002-1004.

Klepper, B., R. W. Rickman, and P. M. Chevalier. 1987. Wheat plant growth in conservation tillage. Pages 93-107. In: STEEP-Soil Conservation Concepts and Accomplishments (L. F. Elliott, editor). Washington State University, Pullman, WA.

Klepper, B., R. W. Rickman, and C. M. Peterson. 1982b. Quantitative characterization of vegetative development in small cereal grains. Agronomy Journal 74:789-792.

Klepper, B., R. W. Rickman, and H. M. Taylor. 1983b. Farm management and the function of field crop root systems. Agricultural Water Management 7:115-141.

Klepper, B., R. W. Rickman, S. Waldman, and P. Chevalier. 1998. The physiological life cycle of wheat: Its use in breeding and crop management. Euphytica 100:341-347.

Klepper, B., R. W. Rickman, J. F. Zuzel, and S. E. Waldman. 1988. Use of growing degree days to project sample dates for cereal crops. Agronomy Journal 80:850-852.

Klepper, B., and H. M. Taylor. 1979. Limitations to current models describing water uptake by root systems. Pages 51-65. In: The Soil-Root Interface (J. L. Harley and R. S. Russell, editors). Academic Press, New York.

Klepper, B., T. W. Tucker, and B. D. Dunbar. 1983c. A numerical index to assess early inflorescence development in wheat. Crop Science 23:206-208.

Klepper, B., J. F. Zuzel, and D. E. Wilkins. 1990. Soil Conservation. Pages 392-394. In: 1991 McGraw-Hill Yearbook of Science and Technology. McGraw-Hill, NY.

Koehler, F. E., V. L. Cochran, and P. E. Rasmussen. 1987. Fertilizer placement, nutrient flow, and crop response in conservation tillage. Pages 57-65. In: STEEP-Conservation Concepts and Accomplishments (L. F. Elliott, editor). Washington State University, Pullman, WA.

Kolding, M. F. 1979. Harney County Spring Cereal Yield and Observation Trials. Oregon Agricultural Experiment Station Special Report 533. 12 pages.

Kolding, M. F., and R. J. Metzger. 1985. Triticale in Oregon. Pages 51-55. In: Triticale (R. A. Forsberg,editor). Crop Science Society of America Special Publication No. 9. Madison, WI.

Korsching, P. F., and D. J. Wysocki. 1985. Observations on teaching an interdisciplinary applied course. Rural Sociologist 5:154-157.

Kraft, J. M., and R. R. Allmaras. 1985. Pea-root pathogen populations in relation to soil structure, compaction, and water content. Pages 203-205. In: Ecology and Management of Soilborne Plant Pathogens (C. A. Parker, A. D. Rovira, K. J. Moore, and P. T. W. Wong, editors). American Phytopathological Society, St. Paul, MN. 358 pages.

Kraft, J. M., and D. E. Wilkins. 1989. The effects of pathogen numbers and tillage on root disease, root length, and seed yields in green peas. Plant Disease 73:884-887.

Kraft, J. M., D. E. Wilkins, A. G. Ogg, Jr., L. Williams, and G. S. Willett. 1991. Integrated Pest Management for Green Peas in the Blue Mountain Region. Washington Cooperative Extension Bulletin 1599. 30 pages.

Krauss, H. A., and R. R. Allmaras. 1982. Technology masks the effects of soil erosion on wheat yields - a case study in Whitman County, Washington. Pages 75-86. In: Determinants of Soil Loss Tolerance. (B. L. Schmidt, editor). ASA Special Publication 45. American Society of Agronomy, Madison, WI. 153 pages.

Kroese, D. R., S. Bag, K. E. Frost, T. D. Murray, and C. H. Hagerty. 2018. Diagnostic Guide: Wheat Soil-Borne Mosaic. Plant Health Progress 19:163-167.

Kronstad, W. E., W. H. Foote, and M. F. Kolding. 1972a. Registration of Yamhill wheat. Crop Science 12:398.

Kronstad, W. E., W. H. Foote, M. F. Kolding, and C. R. Rohde. 1972b. Registration of Hyslop wheat. Crop Science 12:398.

Kronstad, W. E., M. F. Kolding, P. K. Zwer, and R. S. Karow. 1994a. Registration of 'Gene' wheat. Crop Science 34:538.

Kronstad, W. E., M. F. Kolding, P. K. Zwer, and R. S. Karow. 1994b. Registration of 'Hoff' wheat. Crop Science 34:538.

Kronstad, W. E., C. R. Rohde, M. F. Kolding, and R. J. Metzger. 1976. Registration of McDermid wheat. Crop Science 16:745.

Kronstad, W. E., C. R. Rohde, M. F. Kolding, and R. J. Metzger. 1978. Registration of Stephens wheat. Crop Science 18:1097.

Kumar, D., A. Juneja, W. Hohenschuh, J. D. Williams, and G. S. Murthy. 2012. Chemical composition and bioethanol potential of different plant species found in Pacific Northwest conservation buffers. Journal of Renewable and Sustainable Energy 4:063114

Lane, M. C. 1931. The Great Basin Wireworm in the Pacific Northwest. USDA Farmers' Bulletin No. 1657. US Government Printing Office, Washington, D.C. 8 pages.

Larson, W. E., and R. R. Allmaras. 1971. Management factors and natural forces as related to compaction. Pages 367-427. In: Compaction of Agricultural Soils. (K. K. Barnes, W. M. Carleson, H. M. Taylor, R. I. Throckmorton, and G. E. Vanden Berg, editors). American Society of Agricultural Engineers Monograph, St. Joseph, MI.

Leggett, G. E., R. E. Ramig, L. C. Johnson, and T. W. Massee. 1974. Summer fallow in the Northwest. Pages 110-135. In: Summer fallow in the Western United States. USDA Agricultural Research Service Conservation Research Report No. 17. Washington, D.C. 160 pages.

Leite, L. F. C., S. Milak, E. S. Medonca, H. F. Gollany, P. C. Doraiswamy, and H. J. Causarano. 2009. Modeling organic carbon dynamics under no-tillage and plowed systems in tropical soils of Brazil using CQESTR. Soil and Tillage Research 102:118-125.

Letey, J., R. E. Sojka, D. R. Upchurch, D. K. Cassel, K. R. Olson, W. A. Payne, S. E. Petrie, G. H. Price, R. J. Reginato, H. D. Scott, P. J. Smethurst, and G. B Triplett. 2003. Deficiencies in the soil quality concept and its application. Journal of Soil and Water Conservation 58:180-187.

Liang, Y., H. T. Gollany, R. W. Rickman, S. L. Albrecht, R. F. Follett, W. W. Wilhelm, J. M. Novak, and C. L. Douglas, Jr. 2008. CQESTR simulation of management practice effects on long-term soil organic carbon. Soil Science Society of America Journal 72:1486-1492.

Liang, Y., H. T. Gollany, R. W. Rickman, S. L. Albrecht, R. F. Follett, W. W. Wilhelm, J. M. Novak, and C. L. Douglas, Jr. 2009. Simulating soil organic matter with CQESTR (v.2.0): Model description and validation against long-term experiments across North America. Ecological Modelling 220:568-581.

Liebig, M. A., J. A. Morgan, J. D. Reeder, B. H. Ellert, H. T. Gollany, and G. E. Schuman. 2005. Greenhouse gas contributions and mitigation potential of agricultural practices in northwestern USA and western Canada. Soil and Tillage Research 83:25-52.

Long, D. S., J. U. H. Eitel, and D. R. Huggins. 2009. Assessing nitrogen status of dryland wheat using canopy chlorophyll content index. Plant Management Network. Online at doi:10.1094/CM-2009-1211-01-RS.

Long, D. S., R. E. Engel, and F. M. Carpenter, F. M. 2005. On-combine sensing and mapping of wheat protein concentration. Crop Management; on-line at doi:10.1094/CM-2005-0527-01-RS.

Long, D. S., R. E. Engel, and M. C. Siemens. 2008. Measuring grain protein concentration with in-line near infrared reflectance spectroscopy. Agronomy Journal 100:247-252.

Long, D., and J. McCallum. 2013. Mapping straw yield using on-combine light detection and ranging (lidar). International Journal of Remote Sensing 34:17, 6121-6134.

Long, D., and J. McCallum. 2015. On-combine, multi-sensor data collection for post-harvest assessment of environmental stress in wheat. Precision Agriculture 16:492-504.

Long, D., J. McCallum, C. Martin, and S. Capalbo. 2016a. Net returns from segregating dark northern spring wheat by protein concentration during harvest. Agronomy Journal 108:1503-1513.

Long, D., J. McCallum, C. Reardon and R. Engel. 2017a. Adapting the nitrogen replacement approach to dryland spring wheat in the Pacific Northwest. Crops and Soils 50: 34-37.

Long, D. S., J. D. McCallum, C. L. Reardon, and R. E. Engel. 2017b. Nitrogen requirement to change protein concentration of spring wheat in Semiarid Pacific Northwest. Agronomy Journal 109:675-683.

Long, D. S., J. D. McCallum, and P. A. Scharf. 2013. Optical-mechanical system for on-combine segregation of wheat by grain protein concentration. Agronomy Journal 105:1529-1535.

Long, D. S., J. D. Whitmus, R. E. Engel, and G. W. Brester. 2015. Net returns from terrain-based variable-rate nitrogen management on dryland spring wheat in northern Montana. Agronomy Journal 107:1055-1067.

Long, D. S., F. L. Young, W. F. Schillinger, C. L. Reardon, J. D. Williams, B. L. Allen, W. L. Pan, and D. J. Wysocki. 2016b. Development of dryland oilseed production systems in northwestern region of the USA. BioEnergy Research 9:412-429.

Lorang, J. E., C. H. Hagerty, R. Lee, P. McClean, and T. Wolpert. 2018. Genetic analysis of victorin sensitivity and identification of a causal nucleotide-binding site leucine-rich repeat gene in *Phaseolus vulgaris*. Molecular Plant-Microbe Interactions 31:1069-1074.

Lucas, P., R. W. Smiley, and H. P. Collins. 1993. Decline of Rhizoctonia root rot on wheat in soils infested with *Rhizoctonia solani* AG-8. Phytopathology 83:260-265.

Lutcher, L. K, D. A. Horneck, D. J. Wysocki, J. M. Hart, S. E. Petrie, and N. W. Christensen. 2007a. Winter wheat in summer-fallow systems-intermediate precipitation zone. Oregon State University Extension Service Fertilizer Guide FG80-E. Corvallis, OR.

Lutcher, L. K, D. A. Horneck, D. J. Wysocki, J. M. Hart, S. E. Petrie, and N. W. Christensen. 2007b. Winter wheat in summer-fallow systems-low precipitation zone. Oregon State University Extension Service Fertilizer Guide FG80-E. Corvallis, OR.

Lutcher, L. K., D. A. Horneck, D. J. Wysocki, J. M. Hart, S. E. Petrie, and N. W. Christensen. 2005a. Winter wheat and spring grains in continuous cropping systems-intermediate precipitation zone. Oregon State University Extension Service Fertilizer Guide FG82-E. Corvallis, OR.

Lutcher, L. K., D. A. Horneck, D. J. Wysocki, J. M. Hart, S. E. Petrie, and N. W. Christensen. 2005b. Winter wheat in summer-fallow systems-low precipitation zone. Oregon State University Extension Service Fertilizer Guide FG80-E. Corvallis, OR.

Lutcher, L. K., N. W. Christensen, W. F. Schillinger, D. J. Wysocki, and S. B. Wuest. 2012. Phosphorus fertilization of late-planted winter wheat in no-till fallow. Pacific Northwest Extension Bulletin PNW 631. Corvallis, OR. 6 pages.

Lutcher, L. K., W. F. Schillinger, S. B. Wuest, N. W. Christensen, and D. J. Wysocki. 2010. Phosphorus fertilization of late-planted winter wheat into no-till fallow. Agronomy Journal 102:868-874.

Lutcher, L. K., C. S. Sullivan, M. D. Flowers, C. C. Mundt, D. J. Wysocki, K. E. L. Rhinhart, and J. Marshall. 2016. Performance of hard red winter wheat in late-planted fallow. Pacific Northwest Extension Bulletin PNW 635. Corvallis, OR. 6 pages.

Lutcher, L. K., S. B. Wuest, and T. R. Johlke. 2019. First leaf emergence force of three deep-planted winter wheat cultivars. Crop Science 59:772-777.

Lyon, D.J., D. A. Ball, and A. G. Hulting. 2018. Rattail fescue: Biology and management in Pacific Northwest wheat cropping systems. Pacific Northwest Extension Bulletin 613. Washington State University Extension Service, Pullman. 12 pages.

Lyon, D. J., M. J. Walsh, J. Barroso, J. M. Campbell, and A. G. Hulting. 2019. Harvest weed seed control: Applications for PNW Wheat Production Systems. Pacific Northwest Extension Bulletin 730. Washington State University Extension Service, Pullman. 12 pages.

Machado, S. 2006. Demarcating management zones for site specific farming using electromagnetic induction and yield maps in eastern Oregon. Crop Management Journal. Online publication: http://www.plantmanagementnetwork.org/sub/cm/research/2006/zones/SiteSpecific.pdf

Machado, S. 2007. Allelopathic potential of various plant species on downy brome: Implications for weed control in wheat production. Agronomy Journal 99:127-132.

Machado, S. 2009. Does intercropping have a role in modern agriculture? Journal of Soil and Water Conservation 64:55A-57A.

Machado, S. 2011. Soil organic carbon dynamics in the Pendleton long-term experiments: Implications for biofuel production in Pacific Northwest. Agronomy Journal 103:253–260.

Machado, S, E. D. Bynum, Jr., T. L. Archer, J. Bordovsky, E. Segarra, K. Bronson, D.M. Nesmith, D.T. Rosenow, and G. C. Peterson. 2002a. Spatial and temporal variability of sorghum grain yield: Site-specific relations of soil, water, pests, and diseases. Precision Agriculture 3:389-406.

Machado, S., E. D. Bynum, Jr., T. L. Archer, R. J. Lascano, L. T. Wilson, J. Bordovsky, E. Segarra, K. Bronson, D. M. Nesmith, and W. Xu. 2000. Spatial and temporal variability of corn grain yield: Site-specific relationships of biotic and abiotic factors. Precision Agriculture 2:343-360.

Machado, S, E. D. Bynum, Jr., T. L. Archer, R. J. Lascano, L. T. Wilson, J. Bordovsky, E. Segarra, K. Bronson, D. M. Nesmith, and W. Xu. 2002b. Spatial and temporal variability of corn growth and grain yield: Implications for site-specific farming. Crop Science 42:1564-1576.

Machado, S., C. Humphreys, B. Tuck, and M. Corp. 2006a. Seeding date, plant density, and cultivar effects on chickpea yield and seed size in eastern Oregon. Crop Management Journal. Online publication: http://www.plantmanagementnetwork.org/sub/cm/research/2006/chickpea/ ChickpeaYieldSize.pdf

Machado, S., D. M. Nesmith, K. Bronson, R. J. Loscano, E. Segarra, L. T. Wilson, T. L. Archer, E. D. Bynum Jr., J. Bordovsky, C. Peterson, and D. T. Rosenow. 2002c. Spatial and temporal variability of sorghum grain yield: Influence of soil, water, pests, and diseases relationships. Precision Agriculture 3:389-406.

Machado, S., and G. M. Paulsen. 2001. Combined effects of drought and high temperature on water relations of wheat and sorghum. Plant and Soil 233:179-187.

Machado, S., K. Rhinhart, and S. Petrie. 2006b. Long-term cropping systems effects on soil organic carbon sequestration in Eastern Oregon. Journal of Environmental Quality 35:1548-1553.

Machado, S., and S. Petrie. 2006. Analysis of unreplicated experiments: Introduction. Crop Science 46:2474-2475.

Machado, S., S. E. Petrie, K. Rhinhart, and A. Qu. 2007. Long-term continuous cropping in the Pacific Northwest: Tillage and fertilizer effects on winter wheat, spring wheat, and spring barley. Soil and Tillage Research 94:473-481.

Machado. S., L. Pritchett, and S. Petrie. 2015. No-tillage cropping systems can replace traditional summer fallow in north-central Oregon. Agronomy Journal 107:1863-1877.

Machado, S., R. Smiley, C. Humphreys, J. Gourlie, S. Easley, R. Whittaker, K. Rhinhart, and M. Siemens. 2006c. Paraplow effects on diseases and grain yield of spring wheat and chickpea, 2002-2003. Biological and Cultural Tests for Control of Plant Diseases. Vol 21:FC057.

Machado, S., B. Tuck, S. Macnab, J. Maley, and J. Igo. 2016. Alternative crops for the Columbia Basin. Oregon State University Extension Service Bulletin 8915. 32 pages.

Macnab, A. W., and R. E. Ramig. 1987. Tillage and cropping system alternatives for low rainfall areas. Pages 395-407. In: STEEP-Soil Conservation Concepts and Accomplishments (L.F. Elliott, editor). Washington State University, Pullman, WA.

Marshall, J. M., and R. W. Smiley. 2016. Resistance and tolerance of spring barley to *Heterodera avenae*. Plant Disease 100:396-407.

Martin, J. F. 1932. The cold resistance of Pacific Coast spring wheats at various stages of growth as determined by artificial refrigeration. Agronomy Journal 24:871-880.

Martin, J. F. 1936. Reaction of wheat varieties to composites of races of bunt occurring in the Pacific Northwest. Agronomy Journal 28:672-682.

Martin, J. F. 1938. Effect of seed disinfection and delayed sowing on the control of bunt in infested soil. Agronomy Journal 30:870-877.

Martin, J. F., and R. Sprague. 1938. Relative effectiveness of controlling different physiologic races of smut by seed disinfection. Agronomy Journal 30:390-394.

Martin, J. F., and D. E. Stephens. 1931. Correlation between yields of winter wheat varieties grown in various locations in the Columbia Basin of Oregon. Agronomy Journal 23:638-646.

Mashiringwani, N. A., S. Machado, and E. Mtisi. 1992. Wheat. Pages 102-118. In: Small-Scale Agriculture in Zimbabwe: Field Crop Production. Book Two. (E. E. Whingwiri, K. Mashingaidze, and M. Rukuni, editors). Rockwood Publishers, Harare, Zimbabwe.

Mathews, O. R. 1951. Place of summer fallow in the agriculture of the Western States. U.S.D.A. Circular 886, Washington, D.C. 17 pages. (the author included a significant amount of data from Pendleton)

May, W. L., and L. C. Wright. 1948. Report of the Conference Committee of the Sherman County Planning Conference, January 27, 1948. 36 pages.

Mazurak, A. P., and R. E. Ramig. 1962. Aggregation and air-water permeabilities in a chernozem soil cropped to perennial grasses and fallow grain. Journal of Soil Science 94:151-157.

Mazurak, A. P., and R. E. Ramig. 1963. Residual effects of perennial grass sod on the physical properties of a chernozem soil. Soil Science Society of America Proceedings 27:592-595.

Maaz, T. M., W. F. Schillinger, S. Machado, E. Brooks, J. L. Johnson-Maynard, L. E. Young, F. L. Young, I. Leslie, A. Glover, I. J. Madsen, A. Esser, H. P. Collins, and W. L. Pan. 2017. Impact of climate change adaptation strategies on winter wheat and cropping system performance across precipitation gradients in the Inland Pacific Northwest, USA. Frontiers in Environmental Science 5:23. (doi: 10.3389/fenvs.2017.00023)

Mazzola, M., C. L. Reardon, and J. Brown. 2012. Initial *Pythium* species composition and Brassicaceae seed meal type influence extent of *Pythium*-induced plant growth suppression in soil. Soil Biology and Biochemistry 48:20-27.

Mazzola, M., R. W. Smiley, A. D. Rovira, and R. J. Cook. 1996. Characterization of *Rhizoctonia* isolates, disease occurrence and management in cereals. Pages. 259-267. In: *Rhizoctonia* Species: Taxonomy, Molecular Biology, Ecology, Pathology, and Control (B. Sneh, S. Jabaji-Hare, S. Neate, and G. Dijst, editors). Kluwer Academic Publishers, The Netherlands. 578 pages.

McCall, M. A., and H. F. Holtz. 1921. Investigations in Dry Farm Tillage. State College of Washington, Agricultural Experiment Station Bulletin No. 164, Pullman, WA. 56 pages.

McClure, N. R., A. L. Hafenrichter, and J. L. Schwendiman. 1958. Grasses and Legumes for Conservation Farming in North Central Oregon and Adjacent Areas. USDA, Soil Conservation Service M-2188, Portland, Oregon. 41 pages.

McCool, D. K., G. O. George, M. Freckleton, C. L. Douglas, Jr., and R. I. Papendick. 1993. Topographic effect on erosion from cropland. Transactions of the American Society of Agricultural Engineers 36:1067-1071.

McCool, D.K., and J. D. Williams. 2005. Freeze/thaw effects on rill and gully erosion in the northwestern wheat and range region. International Journal of Sediment Research 20:202-210.

McCool, D. K., and J. D. Williams. 2008. Soil erosion by water. In: Ecological Processes. (S. E. Jorgensen and B. D. Fath, editors). Encyclopedia of Ecology 4:3284-3290. Oxford: Elsevier.

McCool, D. K, J. F. Zuzel, J. D. Istok, G. E. Formanek, M. Molnau, and K. E. Saxton. 1987. Erosion processes and prediction for the Pacific Northwest. Pages 187-204. In: STEEP-Soil Conservation Concepts and Accomplishments (L.F. Elliott, editor). Washington State University, Pullman, WA.

McDermid, J. T. 1967. Irrigation Demonstration Plantings in Sherman and Gilliam Counties. An Unpublished Paper. 16 pages.

McDermid, J. T. 1968. Irrigation Studies in Sherman County. An Unpublished Paper. 9 pages.

McKenna, F., K.A. El-Tarabily, S. Petrie, C. Chen, and B. Dell. 2002. Application of actinomycetes to soil to ameliorate water repellency. Letters in Applied Microbiology 35:107-112.

McMaster, G. S., B. Klepper, R. W. Rickman, W. W. Wilhelm, and W. O. Willis. 1991. Simulation of shoot vegetative development and growth of unstressed winter wheat. Ecological Modeling 53:189-204.

Metzger, R. J., C. W. Schaller, and C. R. Rohde. 1979. Inheritance of resistance to common bunt in wheat, C.I. 7090. Crop Science 19:309-312.

Mitchell, A. C., L. Peterson, C. L. Reardon, S. B. Reed, D. E. Culley, M. F. Romine, and G. G. Geesey. 2012. Role of outer membrane c-type cytochromes MtrC and OmcA in *Shewanella oneidensis* MR-1 cell production, accumulation, and detachment during respiration on hematite. Geobiology 10:355-370.

Molnau, M., J. F. Zuzel, J. D. Istok, K. E. Saxton, and D. K. McCool. 1987. Hydrology processes and proceedings in the Pacific Northwest. Pages 159-196. In: STEEP-Soil Conservation Concepts and Accomplishments (L.F. Elliott, editor). Washington State University, Pullman, WA.

Montfort, F., E. L. Klepper, and R. W. Smiley. 1996. Effects of two triazole seed-treatments, triticonazole and triadimenol, on growth and development of wheat. Pesticide Science 46:315-322.

Moore, A., D. J. Wysocki, T. G. Chastain, T. Wilson, and A. DuVal. 2019. Camelina Nutrient Management Guide for the Pacific Northwest. Pacific Northwest Extension Bulletin 718. Corvallis, OR. 5 pages.

Morita, S., and H. P. Collins. 1990. A method to describe root branching. Japanese Journal of Crop Science 59:580-581.

Morrison, J. E., Jr., R. R. Allen, D. E. Wilkins, G. M. Powell, R. D. Grisso, D. C. Erbach, L. P. Herndon, D. L. Murray, G. E. Formanek, D. L. Pfost, M. M. Herron, and D. I. Baumert. 1988. Conservation planter, drill, and air-type seeder selection guideline. Applied Engineering in Agriculture 4:300-309.

Morrison, J. E., Jr., R. R. Allen, D. E. Wilkins, G. M. Powell, R. Grisso, D. C. Erbach, L. P. Herndon, D. L. Murray, G. E. Formanek, D. L. Pfost, M. M. Herron, and D. I. Baumert. 1989. Expert system for selecting conservation planting machines: Planting. Transactions of the American Society of Agricultural Engineers 32:397-401.

Morrison, J. E., R. W. Rickman, D. K. McCool, and K. L. Pfeiffer. 1997. Measurement of wheat residue cover in the Great Plains and Pacific Northwest. Journal of Soil and Water Conservation 52:59-65.

Murray, G. A., D. L. Auld, and F. V. Pumphrey. 1987. Alternate crops for Pacific Northwest rotation and tillage systems. Pages 595-597. In: STEEP-Conservation Concepts and Accomplishments (L.F. Elliott, editor). Washington State University, Pullman, WA.

Murray, T. D., W. W. Bockus, R. L. Bowden, R. M. Hunger, and R. W. Smiley. 2016. Diseases of wheat (*Triticum* spp. L.): Names of diseases and pathogens officially recognized by the American Phytopathological Society. APS Press, St. Paul, MN.

Murray, T. D., H. R. Pappu, and R. W. Smiley. 2009. First report of soilborne wheat mosaic virus on *Triticum aestivum* in Washington State. Online. Plant Health Progress doi: 10.1094/PHP-2009-1204-01-BR.

Nairn, J. 1956. Evaluation of Dry Land Crop Rotation Experiments at Sherman Branch Experiment Station, Oregon. Oregon Agricultural Experiment Station Miscellaneous Paper No. 23. 19 pages.

Nash, P. R., H. T. Gollany, M. A. Liebig, J. J. Halvorson, D. W. Archer, and D. L. Tanaka. 2018. Simulated soil organic matter responses to crop rotation, tillage, and climate change in North Dakota. Journal of Environmental Quality 47:654-662.

Nash, P. R., H. T. Gollany, J. M. Novak, P. J. Bauer, P. G. Hunt and D. L. Karlen. 2018. Simulated soil organic carbon response to tillage, yield, and climate change in the southeastern Coastal Plains. Journal of Environmental Quality 47:663-673.

Nash, P. R., H. T. Gollany and U. M. Sainju. 2018. CQESTR-simulated response of soil organic carbon to management, yield, and climate change in the northern Great Plains region. Journal of Environmental Quality 47:674-683.

Nesse, P. E., and D. A. Ball. 1994. Downy brome. Pacific Northwest Extension Publication PNW 474. Corvallis, OR. 4 pages.

Noori, F., D. N. Moss, and F. E. Bolton. 1985. Water injection at seeding of winter wheat. Agronomy Journal 77:906-908.

Oblath, E., T. Isbell, M. Berhow, B. Allen, D. Archer, J. Brown, R. Gesch, J. Hatfield, J. Jabro, J. Kiniry, and D. Long. 2016. Development of near-infrared spectroscopy calibrations to measure quality characteristics in intact *Brassica* germplasm. Industrial Crops and Products 89:52-58.

Ogg, A. G., Jr., R. W. Smiley, K. S. Pike, J. P. McCaffrey, D. C. Thill, and S. S. Quisenberry. 1999. Integrated pest management for conservation systems. Pages 97-128. In: Advances in Conservation Farming. (E. L. Michalson, R. I. Papendick, and J. E. Carlson, editors). CRC Press, Boca Raton, LA. 233 pages.

Oldenstadt, D. L., R. E. Allan, G. W. Bruehl, D. A. Dillman, E. L. Michalson, R. I. Papendick, and D. J. Rydrych. 1982. Solutions to environmental and economic problems (STEEP). Science 217:904-909.

Oveson, M. M. 1940. Examples of Accomplishments and Projects at the Sherman Branch of the Oregon Agricultural Experiment Station in Cooperation with the U.S. Bureau of Plant Industry from 1909 to 1940. An Unpublished Station Summary. 8 pages.

Oveson, M. M., 1966. Conservation of soil nitrogen in a wheat summer fallow farming practice. Agronomy Journal 58:444-447.

Oveson, M. M., and A. P. Appleby. 1971. Influence of tillage management in a stubble mulch fallow-winter wheat rotation with herbicide weed control. Agronomy Journal 63:19-20.

Oveson, M. M., and R. S. Besse. 1967. The Pendleton Experiment Station: Its development, program and accomplishments … 1928 to 1966. Oregon Agricultural Experiment Station Special Report 233. Corvallis, OR. 20 pages.

Oveson, M. M., and W. E. Hall. 1948. Union Pacific Educational Car; The Dalles, Oregon: Results from the Sherman Branch Experiment Station. An unpublished 3-page paper.

Oveson, M. M., and W. E. Hall. 1957. Longtime Tillage Experiments on Eastern Oregon Wheat Land. Agricultural Experiment Station Technical Bulletin 39, Oregon State College and U.S.D.A.-Agricultural Research Service, Corvallis. 47 pages.

Oveson, M. M., and W. L. Powers. 1931. Modification of soil nitrogen and organic matter by Austrian winter peas. Journal of the American Society of Agronomy 23:372-387.

Pan, W. L., D. R. Huggins, G. L. Malzer, C. L. Douglas, Jr., and J. L. Smith. 1997. Field heterogeneity in soil-plant nitrogen relationships: implications for site-specific management. Pages 81-99. In: The State of Site-Specific Management for Agriculture (F. J. Pierce and E. J. Sadler, editors). ASA Miscellaneous Publication. American Society of Agronomy, Madison, WI. 430 pages.

Pan, W. L., W. F. Schillinger, F. L. Young, E. M. Kirby, G. G. Yorgey, K. A. Borrelli, E. S. Brooks, V. A. McCracken, T. M. Maaz, S. Machado, I. J. Madsen, J. L. Johnson-Maynard, L. E. Port, K. Painter, D. R. Huggins, A. D. Esser, H. P. Collins, C. O. Stockle, and S. D. Eigenbrode. 2017. Integrating historic agronomic and policy lessons with new technologies to drive farmer decisions for farm and climate: The case of Inland Pacific Northwestern U.S. Frontiers in Environmental Science 5:76 (doi: 10.3389/fenvs.2017.00076).

Park, E. Y., B.-K. Baik, S. Machado, H. Gollany, and E. P. Fuerst. 2015. Functional and nutritional characteristics of soft wheat grown in no-till and conventional cropping systems. Cereal Chemistry 92: 332-338.

Park, K. W., C. A. Mallory-Smith, D. A. Ball, and G. W. Mueller-Warrant. 2004. Ecological fitness of acetolactate synthase inhibitor-resistant and susceptible downy brome (*Bromus tectorum*) biotypes. Weed Science 52:768-773.

Parton, W. J., and P. E. Rasmussen. 1994. Long-term effects of residue management in wheat-fallow: Century model simulations. Soil Science Society of America Journal 58:530-536.

Paulitz, T., R. Smiley, and R. J. Cook. 2002. Insights into the prevalence and management of soilborne cereal pathogens under direct seeding in the Pacific Northwest U.S.A. Canadian Journal of Plant Pathology 24:416-428.

Payne, W. A. 1997. Managing yield and water use of pearl millet in the Sahel. Agronomy Journal 89:481-490.

Payne, W. A. 1999. Shallow tillage with a traditional West African hoe to conserve soil. Soil Science Society of America Journal 63:972-976.

Payne, W. A., C. Chen, and D. A. Ball. 2004. Agronomic potential of narrow-leafed and white lupins in the inland Pacific Northwest. Agronomy Journal 96:1501-1508.

Payne, W. A., P. E. Rasmussen, C. Chen, and R. E. Ramig. 2001. Assessing simple wheat and pea models using data from a long-term tillage experiment. Agronomy Journal 93:250-260.

Payne, W. A., P. E. Rasmussen, C. Chen, R. Goller, and R. E. Ramig. 2000. Precipitation, temperature and tillage effects upon productivity of a winter wheat-dry pea rotation. Agronomy Journal 92:933-937.

Payne, W. A., J. H. Williams, M. M. Keitella, and R. D. Stern. 1998. Crop diversification in the Sahel through use of environmental changes near Faidherbia Albida (Del.) A. Chev. Crop Science 38:1585-1591.

Pennell, R. L. Four New Wheat Varieties Released. Bulletin of the Pacific Northwest Crop Improvement Association, Portland, Oregon. September 29, 1965. 3 pages.

Peterson, C. M., B. Klepper, F. V. Pumphrey, and R. W. Rickman. 1984. Restricted rooting decreases tillering and growth of winter wheat. Agronomy Journal 76:861-863.

Peterson, C. M., B. Klepper, and R. W. Rickman. 1982. Tiller development at the coleoptilar node in winter wheat (*Triticum aestivum* L.). Agronomy Journal 74:781-784.

Peterson, C. M., B. Klepper, and R. W. Rickman. 1989. Seed reserves and seedling development in winter wheat. Agronomy Journal 81:245-251.

Petrie, S. E., D. J. Wysocki, D. A. Horneck, L. K. Lutcher, J. M. Hart, and M. K. Corp. 2005. Winter wheat in continuous cropping systems - high precipitation zone. Oregon State University Extension Service Fertilizer Guide FG84-E. Corvallis, OR.

Petrie, S. E., D. J. Wysocki, D. A. Horneck, L. K Lutcher J. M. Hart, and M. K. Corp. 2007. Winter wheat in continuous cropping systems- high precipitation zone. Oregon State University Extension Service Fertilizer Guide FG84-E. Corvallis, OR.

Phillips, C.L., K. Trippe, C. Reardon, B. Mellbye, S.M. Griffith, G.M. Banowetz, and D. Gady. 2018. Physical feasibility of biochar production and utilization at a farm-scale: A case-study in non-irrigated seed production. Biomass Bioenergy 108: 244-251.

Pikul, J. L., Jr. 1991. Estimating soil surface temperature from meteorological data. Soil Science 151:187-195.

Pikul, J. L., Jr., and R. R. Allmaras. 1984. A field comparison of null-aligned and mechanistic soil heat flux. Soil Science Society of America Journal 48:1207-1214.

Pikul, J. L., Jr., and R. R. Allmaras. 1985. Hydraulic potential in unfrozen soil in response to diurnal freezing and thawing of the soil surface. Transactions of the American Society of Agricultural Engineers 28:164-168.

Pikul, J. L., Jr., and R. R. Allmaras. 1986. Physical and chemical properties of a Haploxeroll after fifty years of residue management. Soil Science Society of America Journal 50:214-219.

Pikul, J. L., Jr., R. R. Allmaras, and G. E. Fischbacher. 1979. Incremental soil sampler for use in summer-fallowed soils. Soil Science Society of America Journal 43:425-427.

Pikul, J. L. Jr., R. R. Allmaras, and S. E. Waldman. 1985. Late season heat flux and water distribution in summer-fallowed haploxerolls. Soil Science Society of America Journal 49:1517-1522.

Pikul, J. L., Jr., L. Boersma, and R. W. Rickman. 1989. Temperature and water profiles during diurnal soil freezing and thawing: Field measurements and simulation. Soil Science Society of America Journal 53:3-10.

Pikul, J. L. Jr., R. E. Ramig, and D. E. Wilkins. 1993. Soil properties and crop yield among four tillage systems in a wheat-pea rotation. Soil and Tillage Research 26:151-162.

Pikul, J. L., Jr, D. E. Wilkins, J. K. Aase, and J. F. Zuzel. 1996. Contour ripping: A tillage strategy to improve water infiltration into frozen soil. Journal of Soil and Water Conservation 51:76-83.

Pikul, J. L., Jr., and J. F. Zuzel. 1990. Heat and water flux in a diurnally freezing and thawing soil. Pages 113-119. In: Proceedings of the International Symposium on Frozen Soil Impacts on Agricultural, Range, and Forest Lands. U.S. Army Corps of Eng. CRREL Spec. Rep. 90-1. Hanover, NH.

Pikul, J. L., Jr., and J. F. Zuzel. 1994. Soil crusting and water infiltration affected by long-term tillage and residue management. Soil Science Society of America Journal 58:1524-1530.

Pikul, J. L., Jr., J. F. Zuzel, and R. N. Greenwalt. 1986. Formation of soil frost as influenced by tillage and residue management. Journal of Soil and Water Conservation 41: 196-199.

Pikul, J. L., Jr., J. F. Zuzel, and R. E. Ramig. 1990. Effect of tillage-induced soil macroporosity on water infiltration. Soil and Tillage Research 17:153-165.

Pikul, J. L., Jr., J. F. Zuzel, and D. E. Wilkins. 1991. Water infiltration into frozen soil: Field measurements and simulation. Pages 357-366. In: Proceedings of the National Symposium on Preferential Flow. American Society of Agricultural Engineers, St. Joseph, MO.

Pikul, J. L., Jr., J. F. Zuzel, and D. E. Wilkins. 1992. Infiltration into frozen soil as affected by ripping. Transactions of the American Society of Agricultural Engineers 35:83-90.

Pimstein, A., J. U. H. Eitel, D. S. Long, I. Mufradi, A. Karnieli, and D. J. Bonfil. 2009. A spectral index to monitor the head-emergence of wheat in semi-arid conditions. Field Crops Research 111:218-225.

Plaza, C., H. Gollany, G. Baldoni , A. Polo, and C. Ciavatta. 2012. Predicting long-term organic carbon dynamics in organically-amended soils using the CQESTR model. Journal of Soil and Sediment 477:486-493.

Poole, G. J., R. W. Smiley, T. C. Paulitz, C. A. Walker, A. H. Carter, D. R. See, and K. Garland-Campbell. 2012. Identification of quantitative trait loci (QTL) for resistance to Fusarium crown rot (*Fusarium pseudograminearum*) in multiple assay environments in the Pacific Northwest US. Theoretical & Applied Genetics 125:91-107.

Poole, G. J., R. W. Smiley, C. Walker, D. Huggins, R. Rupp, J. Abatzoglou, K. Garland-Campbell, and T. C. Paulitz. 2014. Effect of climate on the distribution of *Fusarium* species causing crown rot of wheat in the Pacific Northwest of the US. Phytopathology 103:1130-1140.

Porter, J. R., B. Klepper, and R. K. Belford. 1986. A model (WHTROOT) which synchronizes root growth and development with shoot development for winter wheat. Plant and Soil 92:133-145.

Powelson, R. L., and C. R. Rohde. 1972. The influence of date of seeding on control of Cercosporella foot rot with benomyl. Plant Disease Reporter 56:178-180.

Pumphrey, F. V. 1961. Winter wheat fertilization in Northeast Oregon. Oregon Agricultural Experiment Station Circular of Information 610. 8 pages.

Pumphrey, F. V. 1963. Sulfur and phosphorus fertilization of alfalfa and clover in Northeast Oregon. Oregon Agricultural Experiment Station Circular of Information 619. 10 pages.

Pumphrey, F. V. 1965. Residue management in Kentucky bluegrass (*Poa pratensis* L.) and red fescue (*Festuca rubra* L.) seed fields. Agronomy Journal 57:559-561.

Pumphrey, F. V. 1968. Wheat yield and protein content as predictors for nitrogen fertilization in northeast Oregon. Oregon Agricultural Experiment Station Special Report 259. 8 pages.

Pumphrey, F. V. 1970. Semidwarf winter wheat response to early spring clipping and grazing. Agronomy Journal 62:641-643.

Pumphrey, F. V. 1971. Grass species growth on a volcanic ash-derived soil cleared of forest. Journal of Range Management 24:200-203.

Pumphrey, F. V. 1980. Precipitation, temperature, and herbage relationships for a pine woodland site in northeastern Oregon. Journal of Range Management 33:307-310.

Pumphrey, F. V. 1982. Crop management and wind erosion. Pages 85-97. In: Crop Production using Cover Crops and Sods as Living Mulches (J. C. Miller, editor). Proceedings of the International Plant Protection Center Document 4S-A-82. Oregon State Univ., Corvallis, OR.

Pumphrey, F. V., B. L. Klepper, R. W. Rickman, and D. C. Hane. 1980. Sandy soil and soil compaction. Oregon Agricultural Experiment Station Circular of Information 687. 4 pages.

Pumphrey, F. V., M. F. Kolding, and S. Broich. 1987a. Intensively Managed Irrigated Hard Red Winter Wheat Production. Oregon Agricultural Experiment Station Bulletin 670. 22 pages.

Pumphrey, F. W., and D. P. Moore. 1965a. Diagnosing sulfur deficiency of alfalfa (*Medicago sativa* L.) from plant analysis. Agronomy Journal 57:364-366.

Pumphrey, F. W., and D. P. Moore. 1965b. Sulfur and nitrogen content of alfalfa herbage during growth. Agronomy Journal 57:237-239.

Pumphrey, F. V., and D. P. Moore. 1973. "Sick" alfalfa. Oregon Agricultural Experiment Station Circular of Information 644. 7 pages.

Pumphrey, F. V., M. M. Oveson, E. N. Hoffman, and L. A. Fitch. 1967. Alfalfa variety tests in the Columbia Basin, Blue Mountains, and Snake River Valley. Oregon Agricultural Experiment Station Circular of Information 625. 5 pages.

Pumphrey, F. V., and R. E. Ramig. 1990. Field response of peas to excess heat during the reproductive stage of growth. Journal of the American Society of Horticultural Sciences 115:898-900.

Pumphrey, F. V., R. E. Ramig, and R. R. Allmaras. 1975. Yield-tenderness relationships in 'Dark Skinned Perfection' peas. Journal of the American Society of Horticultural Science 100:507-509.

Pumphrey, F. V., R. E. Ramig, and R. R. Allmaras. 1979. Field response of peas (*Pisum sativum* L.) to precipitation and excess heat. Journal of the American Society of Horticultural Sciences 104:548-550.

Pumphrey, F. V., and P. E. Rasmussen. 1982. Winter wheat fertilization in the Northeast Intermountain Region of Oregon. Oregon Agricultural Experiment Station Circular of Information 691. 21 pages.

Pumphrey, F. V., and P. E. Rasmussen. 1995. The Pendleton Agricultural Research Center, 1967-1992. Oregon Agricultural Experiment Station Special Report 950. 38 pages.

Pumphrey, F. V., and G. L. Rubenthaler. 1983. Lodging effects on yield and quality of soft white wheat. Cereal Chemistry 60:268-270.

Pumphrey, F. V., and R. K. Schwanke. 1974. Effects of irrigation on growth, yield, and quality of peas for processing. Journal of the American Society of Horticultural Science 99:104-106.

Pumphrey, F. V., D. E. Wilkins, D. C. Hane, and R. W. Smiley. 1987b. Influence of tillage and nitrogen fertilizer on Rhizoctonia root rot (bare patch) of winter wheat. Plant Disease 71:125-127.

Pusey, P. L., V. O. Stockwell, C. L. Reardon, T. H. M. Smits, and B. Duffy. 2011. Antibiosis activity of *Pantoea agglomerans* biocontrol strain E325 against *Erwinia amylovora* on apple flower stigmas. Phytopathology 101:1234-1241.

Rainbolt, C., D. A. Ball, D. Thill, J. Yenish. 2004a. Management Strategies for Preventing Herbicide-Resistant Grass Weeds in Clearfield Wheat Systems. Pacific Northwest Extension Publication PNW 572. 8 pages.

Rainbolt, D. R., D. C. Thill, and D. A. Ball. 2001. Response of rotational crops to BAY MKH 6561. Weed Technology 15:365-374.

Rainbolt, C. R., D. C. Thill, J. Yenish, and D. A. Ball. 2004b. Herbicide-resistant grass weed development in imidazolinone-resistant wheat: Weed biology and herbicide rotation. Weed Technology 18:860-868.

Ramig, R. E. 1979. USDA Land and Water Conservation Task Force, Impact and Capability of Soil and Water Conservation Practices: 1:95; 2:255; 3:336. U.S. Dept. of Agriculture, Hyattsville, MD 20791.

Ramig, R. E. 1988. Water conservation and use in the semiarid Pacific Northwest. Pages 512-513. In: Challenges in Dryland Agriculture - A Global Perspective (P. W. Unger, T. V. Sneed, W. R. Jordan, and R. W. Jensen, editors). Proceedings of the International Conference on Dryland Farming. Texas Agricultural Experiment Station, Amarillo, TX. 965 pages.

Ramig, R. E., R. R. Allmaras, and R. I. Papendick. 1983. Water Conservation: Pacific Northwest. Pages 105-124. In: Dryland Agriculture (H. E. Dregne and W. O. Willis, editors). ASA Monograph 23. American Society of Agronomy, Madison, WI.

Ramig, R. E., and L. G. Ekin. 1987. Conservation tillage systems for annually cropped wheat in the Pacific Northwest. Journal of Soil and Water Conservation 42:53-55.

Ramig, R. E., and D. C. Maxwell. 1984. Small grain residue management. Oregon State Univ. Ext. Serv. Spec. Rep. 699.

Ramig, R. E., and A. P. Mazurak. 1964. Wheat stubble management. I. Influence on some physical properties of a chernozem soil. Soil Science Society of America Proceedings 28:554-557.

Ramig, R. E., and H. E. Rhoades. 1963. Interrelationships of soil moisture level at planting time and nitrogen fertilization of winter wheat production. Agronomy Journal 55:123-127.

Ramig, R. E., and R. W. Rickman. 1985. Description of data collection sites and methods. D. Pacific Northwest: Winter Wheat. p. 27-41. In (W. O. Willis, editor). ARS Wheat Yield Project. USDA, ARS ARS-38.

Ramig, R. E., P. E. Rasmussen, R. R. Allmaras, and C. M. Smith. 1975. Nitrogen-sulfur relations in soft white winter wheat. I. Yield response to fertilizer and residual sulfur. Agronomy Journal 67:219-228.

Ramig, R. E., K. E. Saxton, T. W. Massee, G. S. Campbell, and D. C. Thill. 1987. Water conservation under reduced tillage systems. p. 125-136. In (L. F. Elliott, editor) STEEP-Soil Conservation Concepts and Accomplishments. Washington State Univ., Pullman, WA

Rampton, H. H. 1957. Forage, Seed, and Specialty Crop Variety Recommendations for Oregon. Oregon Agricultural Experiment Station Circular of Information 577. 28 pages.

Rasmussen, P. E. 1985. Fertilizer management in conservation tillage of Pacific Northwest cereals. p. 16-17. In Better Crops with Plant Food. Potash & Phosphate Institute, Atlanta, GA

Rasmussen, P. E. 1988. Nitrogen and sulfur effects on water use efficiency of winter wheat. Pages 473-475. In: Challenges in Dryland Agriculture - A Global Perspective (P. W. Unger, T. V. Sneed, W. R. Jordan, and R. W. Jensen, editors). Proceedings of the International Conference on Dryland Farming. Texas Agricultural Experiment Station, Amarillo, TX. 965 pages.

Rasmussen, P. E. 1993. Surface residue and nitrogen fertilization effects on no-till wheat. Pages 555-558. In: Plant Nutrition – From Genetic Engineering to Field Practice (N. J. Barrow, editor). Kluwer Academic Publishers.

Rasmussen, P. E. 1995. Effects of fertilizer and stubble burning on downy brome competition in winter wheat. Communications in Soil Science and Plant Analysis 26:951-960.

Rasmussen, P. E. 1996a. Effect of nitrogen, sulfur, and phosphorus sufficiency on nutrient content in white winter wheat. Communications in Soil Science and Plant Analysis 27:585-596.

Rasmussen, P. E. 1996b. Fertility management in dryland conservation cropping systems of the Pacific Northwest. American Journal of Alternative Agriculture 11:108-114.

Rasmussen, P. E., and S. L. Albrecht. 1997. Crop management effects on organic carbon in semi-arid Pacific Northwest soils. Pages 209-219. In: Management of carbon sequestration in soil (R. Lal, J. M. Kimble, R. F. Follett, and B. A. Stewart, editors). CRC Press, Boca Raton, FL.

Rasmussen, P. E., S. L. Albrecht, and R. W. Smiley. 1998a. Soil C and N changes under tillage and cropping systems in semi-arid Pacific Northwest agriculture. In: Tillage and crop management impacts on soil carbon storage (K. Paustian, E. T. Elliott, and M. R. Carter, editors). Soil and Tillage Research 47:197-205.

Rasmussen, P. E., and R. R. Allmaras. 1986. Sulfur fertilization effects on winter wheat yield and extractable sulfur in semiarid soils. Agronomy Journal 78:421-425.

Rasmussen, P. E., R. R. Allmaras, C. R. Rohde, and N. C. Roager, Jr. 1980. Crop residue influences on soil carbon and nitrogen in a wheat-fallow system. Soil Science Society of America Journal 44:596-600.

Rasmussen, P. E., and H. P. Collins. 1991. Long-term impacts of tillage, fertilizer, and crop residue on soil organic matter in temperate semi-arid regions. Advances in Agronomy 45:93-134.

Rasmussen, P. E., H. P. Collins, and R. W. Smiley. 1989. Long-term management effects on soil productivity and crop yield in semi-arid regions of eastern Oregon. Oregon Agricultural Experiment Station Bulletin 675. 57 pages.

Rasmussen, P. E., and C. L. Douglas, Jr. 1991. Effect of rill erosion during early vegetative growth on winter wheat yield. Agronomy Journal 83:729-732.

Rasmussen, P. E., and C. L. Douglas, Jr. 1992. The influence of tillage and cropping-intensity on cereal response to nitrogen, sulfur, and phosphorus. Fertilizer Research 31:15-19.

Rasmussen, P. E., C. L. Douglas, Jr., H. P. Collins, and S. L. Albrecht. 1998b. Long-term cropping system effects on mineralizable nitrogen in soil. Soil Biology and Biochemistry 30:1829-1837.

Rasmussen, P. E., K. W. T. Goulding, J. R Brown, P. R. Grace, H. H. Janzen, and M. Körschens. 1998c. Long-term agroecosystem experiments: Assessing agricultural sustainability and global change. Science 282:893-896.

Rasmussen, P. E., and P. O. Kresge. 1986. Plant response to sulfur in the Western United States. Pages 357-374. In: Sulfur in Agriculture (M.A Tabatabai, editor). ASA Monograph No. 27, American Society of Agronomy, Madison, WI.

Rasmussen, P. E., and W. J. Parton. 1994. Long-term effects of residue management in wheat-fallow: I. Inputs, yield, and soil organic matter. Soil Science Society of America Journal 58:523-530.

Rasmussen, P. E., R. E. Ramig, R. R. Allmaras, and C. M. Smith. 1975. Nitrogen-sulfur relations in soft white winter wheat. II. Initial and residual effects of sulfur application on nutrient concentration, uptake, and N/S ratio. Agronomy Journal 67:224-228.

Rasmussen, P. E., R. E. Ramig, L. G. Ekin, and C. R. Rohde. 1977. Tissue analyses guidelines for diagnosing sulfur deficiency in white wheat. Plant and Soil 46:153-163.

Rasmussen, P. E., R. W. Rickman, and C. L. Douglas, Jr. 1986. Air and soil temperatures during spring burning of standing wheat stubble. Agronomy Journal 78:261-263.

Rasmussen, P.E., R. W. Rickman, and E. L. Klepper. 1997. Residue and fertility effects on yield of no-till wheat. Agronomy Journal 89:563-567.

Rasmussen, P. E., and C. R. Rohde. 1988a. Long-term tillage and nitrogen fertilization effects on organic nitrogen and carbon in a semiarid soil. Soil Science Society of America Journal 52:1114-1117.

Rasmussen, P. E., and C. R. Rohde. 1988b. Stubble burning effects on winter wheat yield and nitrogen utilization under semiarid conditions. Agronomy Journal 80:940-942.

Rasmussen, P. E., and C. R. Rohde. 1989. Soil acidification from ammonium-nitrogen fertilization in moldboard plow and stubble-mulch wheat-fallow tillage. Soil Science Society of America Journal 53:119-122.

Rasmussen, P. E., and C. R. Rohde. 1991. Tillage, soil depth, and precipitation effects on wheat response to nitrogen. Soil Science Society of America Journal 55:121-124.

Rasmussen, P. E., and R. W. Smiley. 1993. The crop residue management experiment. Pages 259-262. In: A Global Directory of Long-Term Agronomic Experiments. Vol. 1. Non-European Experiments. (R. A. Steiner and R. W. Herdt, editors). The Rockefeller Foundation. New York. 318 pages.

Rasmussen, P. E., and R. W. Smiley. 1994. Long-term management effects on soil productivity and crop yield in semi-arid regions of eastern Oregon. Oregon Agricultural Experiment Station Bulletin 675. 57 pages.

Rasmussen, P. E., and R. W. Smiley. 1997. Soil carbon and nitrogen change in long-term agricultural experiments at Pendleton, Oregon. Pages 353-360. In: Soil Organic Matter in Temperate Agroecosystems: Long-term Experiments in North America (E. A. Paul, K. Paustian, E. T. Elliott, and C. V. Cole, editors). CRC Press, Boca Raton, FL. 414 pages.

Rasmussen, P. E., R. W. Smiley, and S. L. Albrecht. 1996a. Long-term residue management experiment: Pendleton, Oregon USA. Pages 391-396. In: Evaluation of Soil Organic Matter Models Using Existing, Long-Term Datasets. NATO ASI Series I: Global Environmental Change. Vol. 38. (D. S. Powlson, P. Smith, and J. U. Smith, editors). Springer-Verlag, Berlin. 429 pages.

Rasmussen, P. E., R. W. Smiley, and S. L. Albrecht. 1996b. Pendleton Residue Management. Pages 133-135. In: Global Change and Terrestrial Ecosystems Report No. 7: Soil Organic Matter Network (SOMNET). (P. Smith, J. U. Smith, and D. S. Powlson, editors). GCTE, Wallingford, U.K. 255 pages.

Rawls, W. J., T. J. Jackson, and J. F. Zuzel. 1980. Comparison of areal snow storage sampling procedures for rangeland watersheds. Nordic Hydrology 11:71-82.

Reardon, C. L., A. Dohnalkova, P. Nachimuthu, D. W. Kennedy, D. Saafari, B. W. Arey, L. Shi, Z. Wang, D. A. Moore, J. S. McLean, D. M. Moyles, M. J. Marshall, J. M. Zahara, J. K. Fredrickson, and A. S. Beliaev. 2010. Role of outer-membrane cytochromes MtrC and OmcA in the biomineralization of ferrihydrite by *Shewanella oneidensis* MR-1. Geobiology 8:56-68.

Reardon, C. L., H. T. Gollany, and S. B. Wuest. 2014a. Diazotroph community structure and abundance in wheat-fallow and wheat-pea crop rotations. Soil Biology and Biochemistry 69:406-412.

Reardon, C. L., T. S. Magnuson, E. S. Boyd, W. D. Leavitt, D. W. Reed, and G. G. Geesey. 2013a. Hydrogenase activity of mineral-associated and suspended populations of *Desulfovibrio desulfuricans* Essex 6. Microbial Ecology 67:318-326.

Reardon, C. L., D. W. Reed, G. G. Geesey, W. D. Leavitt, T. S. Magnuson, and E. S. Boyd. 2014b. Hydrogenase activity of mineral-associated and suspended populations of *Desulfovibrio desulfuricans* Essex 6. Microbial Ecology 67:318-326.

Reardon, C. L., S. L. Strauss, and M. Mazzola. 2013b. Changes in available nitrogen and nematode abundance in response to *Brassica* seed meal amendment of orchard soil. Soil Biology and Biochemistry 57:22-29.

Reardon, C. L., and S. B. Wuest. 2016. Soil amendments yield persisting effects on the microbial communities - a 7-year study. Applied Soil Ecology 101:107-116.

Reardon, C. L., S. B. Wuest, C. J. Melle, A. M. Klein, J. D. Williams, J. Barroso, and D. S. Long. 2019. Soil enzyme activity under minimum and conventional tillage wheat-fallow cropping systems. Soil Science Society of America Journal 83:1100-1110**.**

Reddy, P.M., H. Spiller, S.L. Albrecht and K.T. Shanmugam. 1996. Photodissimilation of fructose to H2 and CO2 by a dinitrogen-fixing cyanobacterium, *Anabaena variabilis*. Applied and Environmental Microbiology 62:1220-1226.

Reese, C. L., D. S. Long, D. E. Clay, S. A. Clay, and D. L. Beck. 2010. Nitrogen and water stress impacts on hard red spring wheat (*Triticum aestivum*) canopy reflectance. Journal of Terrestrial Observation 2:67-86.

Reicosky, D.C., W.D. Kemper, G.W. Langdale, C.L. Douglas, Jr., and P.E. Rasmussen. 1995. Soil organic matter changes resulting from tillage and biomass production. Journal of Soil and Water Conservation 50:253-261.

Riar, D. S., D. A. Ball, J. P. Yenish, and I. C. Burke. 2011. Light-activated, sensor-controlled sprayer provides effective postemergence control of broadleaf weeds in fallow. Weed Technology 25:447-453.

Riar, D. S., D. A. Ball, J. P. Yenish, S. B. Wuest, and M. K. Corp. 2010. Comparison of fallow tillage methods in the intermediate rainfall inland Pacific Northwest. Agronomy Journal 102:1664-1673.

Rickman, R. W. 1970. Soil structure evaluation with audiofrequency vibrations. Soil Science Society of America Journal 34:19-24.

Rickman, R. W. 1971. Sonic radiation for soil mechanical property measurement. Transactions of the American Society of Agricultural Engineers 14:1126-1128.

Rickman, R. W. 1972. Irreversible thermodynamics for stress, strain, and other soil physical property description. Transactions of the American Society of Agricultural Engineers 15:620-626.

Rickman, R. W. 1974. Crust strength and cracking: Part II. Cracking. Pages 39-44. In: Soil Crusts (J. W. Cary and D. D. Evans, editors). Arizona Agricultural Experiment Station Technical Bulletin 214.

Rickman, R. W., R. R. Allmaras, and R. E. Ramig. 1978. Root-sink descriptions of water supply to dryland wheat. Agronomy Journal 70:723-728.

Rickman, R. W., C. L. Douglas, Jr., S. L Albrecht, and J. L. Berc. 2001a. CQESTR-Predicting Carbon sequestration in agricultural cropland and grassland soils. Pages 177-181. In: Agricultural practices and policies for carbon sequestration in soil (J. M. Kimble, R. Lal, and R. F. Follett, editors). CRC Press, Boca Raton, FL. 536 pages.

Rickman, R.W., C.L. Douglas, Jr., S.L. Albrecht and J.L. Berc. 2002. Tillage, crop rotation, and organic amendment effect on changes in soil organic matter. Journal of Environmental Pollution 116:405-411.

Rickman, R.W., C.L. Douglas, Jr., S.L. Albrecht, J. L. Berc, L. Norfleet, and M. Hobbs. 2001b. CQESTR, a field-level farm carbon sequestration planning tool. World Resources Review 13:356-368.

Rickman, R.W., C.L. Douglas, Jr., S.L. Albrecht, L.G. Bundy and J.L. Berc. 2001c. CQESTR: A Model to Estimate Carbon Sequestration in Agricultural Soils. Journal of Soil and Water Conservation 56:237-246.

Rickman, R. W., and B. L. Klepper. 1980. Wet season aeration problems beneath surface mulches in dryland winter wheat production. Agronomy Journal 72:733-736.

Rickman, R. W., and B. Klepper. 1986a. Interaction of stubble management on winter wheat development. In Proceedings of Maximum Wheat Yield Research Systems Workshop. Potash and Phosphate Institute. Denver, CO.

Rickman, R. W., and B. Klepper. 1986b. Wheat development and tillering for maximum production. In Proceedings of Maximum Wheat Yield Research Systems Workshop. Potash and Phosphate Institute. Denver, CO.

Rickman, R. W., and E. L. Klepper. 1987. Predicting wheat development and living ground cover from air temperature after planting. Page 285. In: Proceedings of the 2nd Annual National Wheat Research Symposium. National Association of Wheat Growers Foundation, Washington, D.C.

Rickman, R. W., and B. Klepper. 1991a. Environmentally driven cereal crop growth models. Annual Review of Phytopathology 29:361-380.

Rickman, R. W., and B. Klepper. 1991b. Tillering in wheat. Pages 73-84. In: Physiological Aspects of Predicting Crop Phenology (T. Hodges, editor). CRC Press, Boca Raton, FL.

Rickman, R. W., and B. L. Klepper. 1995. The phyllochron: Where do we go in the future? Crop Science 35:44-49.

Rickman, R. W., B. Klepper, and D. A. Ball. 1995. An algorithm for predicting crown root axes of annual grasses. Agronomy Journal 87:1182-1185.

Rickman, R. W., B. Klepper, and R. K. Belford. 1985a. Developmental relationships among roots, leaves, and tillers in winter wheat. Pages 83-98. In: Wheat Growth and Modelling (W. Day and R. K. Atkins, editors). Bristol, England.

Rickman, R. W., B. L. Klepper, and C. M. Peterson. 1983. Time distributions for describing appearance of specific culms of winter wheat. Agronomy Journal 75:551-556.

Rickman, R. W., B. Klepper, and C. M. Peterson. 1985b. Wheat seedling growth and developmental response to incident photosynthetically active radiation. Agronomy Journal 77:283-287.

Rickman, R. W., B. Klepper, S. Waldman, and J. Brog. 1985c. PLANTEMP 2.0. Oregon State University Miscellaneous Publication EM8308. (Computer Program)

Rickman, R. W., R. E. Ramig, and R. R. Allmaras. 1975. Modeling dry matter accumulation in dryland winter wheat. Agronomy Journal 67:283-289.

Rickman, R. W., and P. E. Rasmussen. 1985. Ground cover estimates for seedling cereal crops. Soil Science Society of America Journal 49:1251-1255.

Rickman, R. W., S. E. Waldman, and B. L. Klepper. 1992. Calculating daily root length density profiles by applying elastic theory to agricultural soils. Journal of Plant Nutrition 15:661-675.

Rickman, R. W., S. E. Waldman, and B. L. Klepper. 1996. MODWht, a development-driven wheat growth simulation. Agronomy Journal 88:176-185.

Rickman, R. W., S. E. Waldman, J. E. Morrison, Jr., and D. K. McCool. 1998. Point transect estimates of residue cover or crop canopy in rows. Transactions American Society Agricultural Engineers 41:1005-1010.

Rohde, C. R. 1956. Performance of wheat varieties in eastern Oregon. Oregon Agricultural Experiment Station Circular of Information 564.

Rohde, C. R. 1963. Effect of nitrogen fertilization on yield, components of yield, and other agronomic characteristics of winter wheat. Agronomy Journal 55:455-458.

Rohde, C. R. 1966a. Performance of barley, oat, and wheat varieties tested in Umatilla, Union, and Wallowa Counties. Oregon Agricultural Experiment Station Circular of Information 614. 16 pages.

Rohde, C. R. 1966b. Registration of Moro wheat. Crop Science 6:502.

Rohde, C. R. 1972. Registration of Adams wheat. Crop Science 12:398.

Rohde, C. R., W. E. Hall, M. J. Johnson, and E. N. Hoffman. 1956. Performance of Wheat Varieties in Eastern Oregon. Oregon Agricultural Experiment Station Circular of Information 564. 13 pages.

Rohde, C. R, W. B. Locke, W. E. Kronstad, M. F. Kolding, and R. J. Metzger. 1978a. Registration of Faro wheat. Crop Science 18:1095.

Rohde, C. R, W. B. Locke, W. E. Kronstad, M. F. Kolding, and R. J. Metzger. 1978b. Registration of Rew wheat. Crop Science 18:1095.

Rohde, C. R., and C. F. Pulham. 1960a. Genetic studies of winter hardiness in barley. Nebraska Agricultural Experiment Station Research Bulletin 193. 48 pages.

Rohde, C. R., and C. F. Pulham. 1960b. Heritability estimates of winter hardiness in winter barley determined by the standard unit method of regression analysis. Agronomy Journal 52:584-586.

Rohde, C. R., and L. H. Purdy, 1961. Effect of seed-treatment fungicides on grain yield and stands of winter and spring wheat. Plant Disease Reporter 45:522-526.

Rohde, C. R, K. H. Van Wagoner, W. E. Kronstad, and G. L. Rubenthaler. 1988. Registration of 'Oveson' wheat. Crop Science 38:1033.

Rood, J., J. Campbell, D. Thill, D. Ball, L. Bennett, J. Yenish, J. Nelson, R. Rood, B. Shafii, and W. Price. 2012. Tillage affects imazamox carryover in yellow mustard. Weed Technology 26:308-315.

Ross, C. R. 1972. Eastern Oregon Windbreak Trees and Shrubs. Oregon State University Extension Service Special Report 371. 16 pages.

Rush, C. M., R. E. Ramig, and J. M. Kraft. 1986. Effects of wheat chaff and tillage on inoculum density of *Pythium ultimum* in the Pacific Northwest. Phytopathology 76:1330-1332.

Russelle, M. P., and F. E. Bolton. 1980. Soil temperature effects on winter wheat and winter barley emergence in the field. Agronomy Journal 72:823-827.

Rydrych, D. J. 1974. Competition between winter wheat and downy brome. Weed Science 22:211-214.

Rydrych, D. J. 1981. Corn cockle (*Agrostemma githago*) competition in winter wheat (*Triticum aestivum*). Weed Science 29:360-363.

Rydrych, D. J. 1985. Inactivation of metribuzin in winter wheat by activated carbon. Weed Science 33:229-232.

Rydrych, D. J., and W. R. Furtick. 1966. A transparent concentrate tank for experimental plot sprayers. Weeds 14:269-271.

Rydrych, D. J., and D. C. Maxwell. 1983. Chemical fallow in dryland grain fields in Oregon. Fact Sheet 299 (FS299). Oregon State University Extension Service, Corvallis, OR. 2 pages.

Rydrych, D. J., and T. J. Muzik. 1968. Downy brome competition and control in dryland wheat. Agronomy Journal 60:279-280.

San Martin, C., D. Andujar, J. Barroso, C. Fernandez-Quintanilla, and J. Dorado. 2016. Weed decision threshold as a key factor for herbicide reductions in site-specific weed management. Weed Technology 30:888-897.

San Martín, C., J. A. Gourlie, and J. Barroso. 2019. Control of volunteer giant reed (*Arundo donax*). Invasive Plant Science and Management 12:43-50.

San Martin, C., D. S. Long, J. A. Gourlie, and J. Barroso. 2018. Suppression of downy brome by reduced tillage fallow in dryland winter wheat. PLoS One 13(9):1-17.

San Martín, C., D. S. Long, J. A. Gourlie, and J. Barroso. 2019. Spring crops in three year rotations reduce weed pressure in winter wheat. Field Crops Research 233:12-20.

San Martin, C., D. Lyon, M. Thorne, and J. Barroso. 2020. Seed retention of major weed species at harvest in the PNW. PLoS One XX: XX-XX (submitted).

San Martin, C., D. J. Lyon, H. C. Wetzel, J. A. Gourlie, and J. Barroso. 2018. Weed control with bicyclopyrone + bromoxynil in wheat. Crop, Forage & Turfgrass Management 4(1):1-6.

Scheuerman, R. D., and A. C. McGregor. 2013. *Harvest Heritage: Agricultural origins and heirloom crops of the Pacific Northwest*. Washington State University Press, Pullman. 186 p.

Schillinger, W. F., and F. E. Bolton. 1993. Fallow water storage in tilled vs. untilled soils in the Pacific Northwest. Journal of Production Agriculture 6:267-269.

Schillinger, W. F., S. O. Guy, R. S. Karow, D. J. Wysocki, and T. G. Chastain. 2012. Camelina: Planting date and method effects on stand establishment and seed yield. Field Crops Research 130:138-144.

Schillinger, W. F., R. I. Papendick, S. O. Guy, P. E. Rasmussen, and C. van Kessel. 2006. Dryland cropping in the western United States. Pages 365-393. In: Dryland Agriculture, 2nd edition (G. A. Peterson, P. W. Unger, and W. A. Payne, editors). Agronomy Monograph No. 23, American Society of Agronomy, Madison, Wisconsin. 928 pages.

Schillinger, W.F. and D.E. Wilkins. 1997. Deep ripping fall-planted wheat after fallow to improve infiltration and reduce erosion. Journal of Soil and Water Conservation 52:190-194.

Schillinger, W. F., and S. B. Wuest. 2014. Wide row spacing for deep-furrow planting of winter wheat. Field Crops Research 168:57-64.

Schillinger, W. F., D. J. Wysocki, T. G. Chastain, S. Guy, and R. Karow. 2014. Camelina: Effects of planting date and method on stand establishment and seed yield. Pacific Northwest Extension Bulletin PNW 661. 10 pages.

Schillinger, W. F., D. J. Wysocki, T. G. Chastain, S. O. Guy, and R. S. Karow. 2012. Camelina: Planting date and method effects on stand establishment and seed yield. Field Crops Research 130:138-144.

Schiwakotia, S., V. D. Zheljazkov, H. T. Gollany, M. Kleber, and B. Xing. 2019. Macronutrients in soil and wheat as affected by a long-term tillage and nitrogen fertilization in winter wheat-fallow rotation. Agronomy Journal 178:1-11.

Schlatter, D.C., C.L. Reardon, J. Johnson-Maynard, E. Brooks, K. Kahl, J. Norby, D. Huggins, and T. C. Paulitz. 2019. Mining the Drilosphere: Bacterial Communities and Denitrifier Abundance in a No-Till Wheat Cropping System. Frontiers in Microbiology 10:1339.

Schumann, G. L., and J. D. McDonald (with "added authors" R. W. Smiley, P. R. Dernoeden, and B. B. Clarke). 1999. Turfgrass Diseases: Diagnosis and Management; An Interactive CD-ROM. APS Press, St. Paul, MN.

Schwendiman, J. L. 1976. Grasses and Legumes for Conservation Use in Semiarid Wheat-Fallow Areas of Eastern Oregon. USDA Soil Conservation Service, Portland, Oregon. 102 pages.

Scudder, H. D., and O. Beaty. 1910. Cooperative Grain Investigations: Eastern Oregon Dry-Farming Substation, Moro, Ore., Annual Report of the Superintendent, 1910. Corvallis, Oregon. 57 pages.

Scudder, H. D., and W. M. Jardine. 1909. Report on Location of Eastern Oregon Dry Farming Experiment Station; Investigations of April and May, 1909. Corvallis, Oregon, May 15, 1909. Oregon Agricultural Experiment Station Bulletin 119. 31 pages.

Shinn, S. L., D. C. Thill, W. J. Price, and D. A. Ball. 1998. Response of downy brome and rotational crops to MON 37500. Weed Technology 12:690-698.

Shiwakoti, S., V. D. Zheljazkov, H. T. Gollany, M. Kleber, and B. Xing. 2019a. Macronutrients in soil and wheat as affected by a long-term tillage and nitrogen fertilization in winter wheat-fallow rotation. Agronomy 9:178. doi:10.3390/agronomy9040178.

Shiwakoti, S., V. D. Zheljazkov, H. T. Gollany, M. Kleber, and B. Xing. 2019b. Micronutrients decline under long-term tillage and nitrogen fertilization. Scientific Reports 9:12020. doi:10.1038/s41598-019-48408-6.

Shiwakoti, S., V. D. Zheljazkov, H. T. Gollany, M. Kleber, B. Xing, and T. Astatkie. 2019c. Micronutrients in the soil and wheat: Impact of 84 Years of organic or synthetic fertilization and crop residue management. Agronomy 9:464; doi.org/10.3390/agronomy9080464.

Shiwakoti, S., V. D. Zheljazkov, H. T. Gollany, B. Xing, and M. Kleber. 2019d. Micronutrient concentrations in soil and wheat decline by long-term tillage and winter wheat-pea rotation. Agronomy 9:359. doi:10.3390/agronomy9070359.

Shiwakoti, S., V. D. Zheljazkov, H. T. Gollany, and B. Xing. 2019f. Effect of tillage on macronutrients in soil and wheat of a long-term dryland wheat-pea rotation. Soil and Tillage Research 190:194-201.

Shiwakoti, S., V.D. Zheljazkov, H.T. Gollany, M. Kleber, B. Xing, and T. Astatkie. 2020. Macronutrient in soils and wheat from long-term agroexperiments reflects variations in residue and fertilizer inputs. *Scientific Reports* **10:**3263. doi.org/10.1038/s41598-020-60164-6.

Shrewsbury, L. H., J. L. Smith, D. R. Huggins, L. Carpenter-Boggs, and C. L. Reardon. 2016. Denitrifier abundance has a greater influence on denitrification rates at larger landscape scales but is a lesser driver than environmental variables. Soil Biology and Biochemistry 103:221-231.

Siemens, M. C. 2006. Effect of guard spacing, guard attachments and reel type on chickpea harvesting losses. Applied Engineering in Agriculture 22:651-657.

Siemens, M. C. and W. E. Coates. 2000. Control system for the mobile truss of a cable drawn farming system. Applied Engineering in Agriculture 16:211-216.

Siemens, M. C., R. F. Correa, and D. E. Wilkins. 2002. Flexible ground-driven residue management wheel. United States Patent No. US 6,345,671 B1.

Siemens, M. C., T. J. Darnell, and D. E. Hulick. 2007a. Performance of two hoe-type air drills sowing green peas in a conservation tillage system. Applied Engineering in Agriculture 23:23-29.

Siemens, M. C., and D. E. Hulick. 2008. A new grain harvesting system for single-pass grain harvest, biomass collection, crop residue sizing, and grain segregation. American Society of Agricultural and Biological Engineers 51:1519-1527.

Siemens, M. C., D. E. Hulick, and B. Jepsen. 2007b. Development of a trigger-on indicator for a weed sensing spray unit. Journal of Applied Crop Science (on-line) doi:10.1094/CM-2007-0515-01-BR.

Siemens, M. C., and D. F. Jones. 2008. Segregation of soft white wheat by density for improved quality. American Society of Agricultural and Biological Engineers 51:1035-1047.

Siemens, M. C. and D. E. Wilkins. 2006. Effect of residue management methods on no-till drill performance. Applied Engineering in Agriculture 22:51-60.

Siemens, M. C., D. E. Wilkins, and R. F. Correa. 2004. Development and evaluation of a residue management wheel for hoe-type no-till drills. Transactions of the American Society of Agricultural Engineers 47:397-404.

Sitton, J., M. Wiese, B. Goates, R. Forster, R. Line, D. Mathre, C. Peterson, R. Smiley, and J. Waldher. 1995. Dwarf Bunt of Winter Wheat in the Northwest. Pacific Northwest Regional Extension Bulletin 489. 6 pages.

Smiley, R. 2005. Plant-Parasitic Nematodes Affecting Wheat Yield in the Pacific Northwest. Oregon State University Extension Publication EM 8887. Corvallis, OR. 4 pages.

Smiley, R. W. 1987. The etiologic dilemma concerning patch diseases of bluegrass turfs. Plant Disease 71:774-781.

Smiley, R. W. 1992. APS Slide Collection for Turfgrass Diseases (with syllabus). American Phytopathological Society, St. Paul, MN.

Smiley, R. W. 1993. Historical perspective of research on ectotrophic root-infecting pathogens of turfgrasses. Pages 1-15. In: Turfgrass Patch Diseases caused by Ectotrophic Root-Infecting Fungi (B. B. Clarke and A. B. Gould, editors). American Phytopathological Society, St. Paul, MN. 161 pages.

Smiley, R. W. 1994. Diseases of turfgrasses. Pages 159-165. In: Common Names for Plant Diseases. American Phytopathological Society, St Paul, MN. 170 pages.

Smiley, R. W. 1996. Diseases of wheat and barley in conservation cropping systems of the semi-arid Pacific Northwest. American Journal of Alternative Agriculture 11:95-103.

Smiley, R. W. 1997a. Rhizoctonia root rot, seed rot, and damping-off. Pages 16-18. In: Compendium of Barley Diseases, 2nd Edition. (D. E. Mathre, editor). American Phytopathological Society, St. Paul, MN. 90 pages.

Smiley, R. W. 1997b. Risk assessment for Karnal bunt occurrence in the Pacific Northwest. Plant Disease 81:689-692.

Smiley, R. W. 1997c. Sharp eye spot. Pages 15-16. In: Compendium of Barley Diseases, 2nd Edition (D.E. Mathre, editor). American Phytopathological Society, St. Paul, MN. 90 pages.

Smiley, R. W. 2009a. Occurrence, distribution and control of *Heterodera avenae* and *H. filipjevi* in the western USA. Pages 35-40. In: Cereal Cyst Nematodes: Status, Research and Outlook. (I. T. Riley, J. M. Nicol, and A. A. Dababat, editors). CIMMYT, Ankara, Turkey. 244 pages.

Smiley, R. W. 2009b. Root-lesion nematodes reduce yield of intolerant wheat and barley. Agronomy Journal 101:1322-1335.

Smiley, R.W. 2009c. Water and temperature parameters associated with winter wheat diseases caused by soilborne pathogens. Plant Disease 93:73-79.

Smiley, R. W. 2010a. Albinism. Pages 139-140. Compendium of Wheat Diseases and Insects, 3rd edition. (W. W. Bockus, R. L. Bowden, R. M. Hunger, W. L. Morrill, T. D. Murray, and R. W. Smiley, editors). APS Press, St. Paul, MN. 171 pages.

Smiley, R. W. 2010b. Chloride and zinc deficient leaf spots. Pages 143-144. Compendium of Wheat Diseases and Insects, 3rd edition. (W. W. Bockus, R. L. Bowden, R. M. Hunger, W. L. Morrill, T. D. Murray, and R. W. Smiley, editors). APS Press, St. Paul, MN. 171 pages.

Smiley, R. W. 2010c. Disease caused by nematodes: Introduction. Pages 87-88. Compendium of Wheat Diseases and Insects, 3rd edition. (W. W. Bockus, R. L. Bowden, R. M. Hunger, W. L. Morrill, T. D. Murray, and R. W. Smiley, editors). APS Press, St. Paul, MN. 171 pages.

Smiley, R. W. 2010d. Physiologic leaf spots. Page 153. Compendium of Wheat Diseases and Insects, 3rd edition. (W. W. Bockus, R. L. Bowden, R. M. Hunger, W. L. Morrill, T. D. Murray, and R. W. Smiley, editors). APS Press, St. Paul, MN. 171 pages.

Smiley, R. W. 2010e. Root diseases, plant health and farming systems. Pages 47-54. In: The Rovira Rhizosphere Symposium, Adelaide, Australia. Online at: http://www.crawfordfund.org/resources/doc.html?publication=324&rtn=88

Smiley, R. W. 2010f. Root-gall nematode. Pages 90-91. Compendium of Wheat Diseases and Insects, 3rd edition. (W. W. Bockus, R. L. Bowden, R. M. Hunger, W. L. Morrill, T. D. Murray, and R. W. Smiley, editors). APS Press, St. Paul, MN. 171 pages.

Smiley, R. W. 2010g. Stunt nematode. Pages 96-97. Compendium of Wheat Diseases and Insects, 3rd edition. (W. W. Bockus, R. L. Bowden, R. M. Hunger, W. L. Morrill, T. D. Murray, and R. W. Smiley, editors). APS Press, St. Paul, MN. 171 pages.

Smiley, R. W. 2012. A fluidizing column for extracting cysts of *Heterodera avenae* from soil. Plant Disease 96:820-826.

Smiley, R. W. 2015a. Effects of cropping systems on dominance of individual *Pratylenchus* species. Pages 315-325. In: Nematodes of Small Grain Cereals: Current Status and Research. A. A. Dababat, H. Muminjanov and R. W. Smiley (editors). FAO, Rome, Italy.

Smiley, R. W. 2015b. Multiplication of *Pratylenchus neglectus* and *P. thornei* on plants other than cereals. pp. 303-313. In: Nematodes of Small Grain Cereals: Current Status and Research. A. A. Dababat, H. Muminjanov and R. W. Smiley (editors).FAO, Rome, Italy.

Smiley, R. W. 2015c. Plant-parasitic nematode affecting small grain cereals in the Pacific Northwest. PNW Extension Bulletin 674. Oregon State University, Corvallis, OR. 8 pages.

Smiley, R. W. 2015d. Root-lesion nematodes: Biology and management in Pacific Northwest wheat cropping systems. PNW Extension Bulletin 617, Oregon State University, Corvallis, OR. 14 pages.

Smiley, R. W. 2016a. Cereal Cyst Nematodes: Biology and Management in Pacific Northwest Wheat, Barley and Oat Crops. PNW Extension Bulletin 620, Oregon State University, Corvallis, OR. 18 pages.

Smiley, R. W. 2016b. Supporting agriculture in wheat country. Oregon State University Sesquicentennial Oral History Project; video, transcript, abstract & biography. Online at http://scarc.library.oregonstate.edu/oh150/smiley/index.html

Smiley, R. W. 2018. Evaluating soilborne pathogens in long-term field trials in USA using PREDICTA® B. Two-page abstract #10.1 in: Proceedings of the 10th Australasian Soilborne Disease Symposium. September 4-8, 2018, Adelaide, Australia (V. V. S. R. Gupta, S. Barnett and S. Kroker, editors). CSIRO Agriculture & Food, Adelaide.

Smiley, R.W. 2019. Fusarium crown rot whitehead symptom as influenced by wheat crop management and sampling date. Plant Disease 103:2612-2623.

Smiley, R.W. 2019. Mechanized method to inoculate field soil to evaluate Fusarium crown rot of wheat. Plant Disease 103:2857-2864.

Smiley, R. W., D. Backhouse, P. Lucas, and T. Paulitz. 2009. Diseases which challenge global wheat production - root, crown, and culm rots. Pages 125-153. In: Wheat Science and Trade, B.F. Carver, ed. Wiley-Blackwell, Ames, IA. 569 pages.

Smiley, R. W., H. P. Collins, and P. E. Rasmussen. 1996a. Diseases of wheat in long-term agronomic experiments at Pendleton, Oregon. Plant Disease 80:813-820.

Smiley, R., R. J. Cook, and T. Paulitz. 2002a. Controlling Root and Crown Diseases of Small Grain Cereals. Oregon State University Extension Publication EM8798. Corvallis, OR. 6 pages.

Smiley, R., R. J. Cook, and T. Paulitz. 2002b. Seed Treatments for Small Grain Cereals. Oregon State University Extension Publication EM 8797. Corvallis, OR. 8 pages.

Smiley, R. W., A. A. Dababat, S. Iqbal, M. G. K. Jones, Z. Tanha Maafi, D. L. Peng, S. A. Subbotin, and L. Waeyenberge. 2017. Cereal cyst nematodes: A complex and destructive group of *Heterodera* species. Plant Disease 101:1692-1720.

Smiley, R. W., P. H. Dernoeden, and B. B. Clarke. 1992a. Compendium of Turfgrass Diseases, 2nd Edition. American Phytopathological Society, St. Paul, MN. 98 pages.

Smiley, R. W., P. R. Dernoeden, and B. B. Clarke. 1999a. (Japanese language version of the Compendium of Turfgrass Diseases, 2nd edition; as translated by T. Tani and A. Tanakai). APS Press, St. Paul, MN.

Smiley, R. W., P. R. Dernoeden, and B. B. Clarke. 1999b. Plagas y Enfermedades de los Céspedes (Spanish language version of the Compendium of Turfgrass Diseases, 2nd edition). APS Press, St. Paul, MN.

Smiley, R. W., P. H. Dernoeden, and B. B. Clarke. 2005a. Compendium of Turfgrass Diseases, 3rd Edition. APS Press, St. Paul, MN. 167 pages.

Smiley, R. W., and M. C. Fowler. 1985a. Arsenate herbicide stress and the incidence of summer patch on Kentucky bluegrass turfs. Plant Disease 69:44-48.

Smiley, R. W., and M. C. Fowler. 1985b. Techniques for inducing summer patch symptoms of *Poa pratensis*. Plant Disease 69:482-484.

Smiley, R. W., and M. C. Fowler. 1986. Turfgrass thatch components and decomposition rates in long-term fungicide plots. Agronomy Journal 78:633-636.

Smiley, R. W., M. C. Fowler, and R. T. Kane. 1985a. Temperature and osmotic potential effects on *Phialophora graminicola* and other fungi associated with patch diseases of *Poa pratensis*. Phytopathology 75:1160-1167.

Smiley, R. W., M. C. Fowler, R. T. Kane, A. M. Petrovic, and R. White. 1985b. Fungicide effects on thatch depth, litter decomposition rate, and growth of Kentucky bluegrass. Agronomy Journal 77:597-602.

Smiley, R. W., M. C. Fowler, and K. L. Reynolds. 1986a. Temperature effects on take-all of cereals, caused by *Phialophora graminicola* and *Gaeumannomyces graminis*. Phytopathology 76:923-931.

Smiley, R. W., and D. E. Giblin. 1986. Root cortical death in relation to infection of Kentucky bluegrass by *Phialophora graminicola*. Phytopathology 76:917-922.

Smiley, R. W., L.-M. Gillespie-Sasse, W. Uddin, H. P. Collins, and M. A. Stoltz. 1993a. Physiologic leaf spot of winter wheat. Plant Disease 77:521-527.

Smiley, R. W., J. A. Gourlie, S. A. Easley, and L.-M. Patterson. 2005b. Pathogenicity of fungi associated with the wheat crown rot complex in Oregon and Washington. Plant Disease 89:949-957.

Smiley, R. W., J. A. Gourlie, S. A. Easley, L.-M. Patterson, and R. G. Whittaker. 2005c. Crop damage estimates for crown rot of wheat and barley in the Pacific Northwest. Plant Disease 89:595-604.

Smiley, R. W., J. A. Gourlie, K. E. L. Rhinhart, J. M. Marshall, M. D. Anderson, and G. P. Yan. 2012a. Influence of nematicides and fungicides on spring wheat in fields infested with soilborne pathogens. Plant Disease 96:1537-1547.

Smiley, R. W., J. A. Gourlie, R. G. Whittaker, S. A. Easley, and K. K. Kidwell. 2004a. Economic impact of Hessian fly (Diptera: Cecidomyiidae) on spring wheat in Oregon and additive yield losses with Fusarium crown rot and lesion nematode. Journal of Economic Entomology 97:397-408.

Smiley, R. W., J. A. Gourlie, G. P. Yan, and K. E. L. Rhinhart. 2014a. Resistance and tolerance of landrace wheat in fields infested with *Pratylenchus neglectus* and *P. thornei*. Plant Disease 98:797-805.

Smiley, R. W., R. E. Ingham, W. Uddin, and G. H. Cook. 1994. Crop sequences for managing cereal cyst nematode and fungal pathogens of winter wheat. Plant Disease 78:1142-1149.

Smiley, R. W., and S. Machado. 2009. *Pratylenchus neglectus* reduces yield of winter wheat in dryland cropping systems. Plant Disease 93:263-271.

Smiley, R.W., and S. Machado. 2020. Fusarium crown rot of winter wheat influenced by resource competition near a tree windbreak. Plant Disease 104:348–357.

Smiley, R. W., S. Machado, J. A. Gourlie, L. C. Pritchett, G. P. Yan, and E. E. Jacobsen. 2013a. Effects of crop rotation and tillage on *Pratylenchus* spp. in the semiarid Pacific Northwest United States. Plant Disease 97:537-546.

Smiley, R. W., S. Machado, J. A. Gourlie, L. C. Pritchett, G. P. Yan, and E. E. Jacobsen. 2013b. Influence of semi-arid cropping systems on root diseases and inoculum density of soilborne pathogens. Plant Disease 97:547-555.

Smiley, R. W., S. Machado, K. E. L. Rhinhart, C. L. Reardon, and S. B. Wuest. 2016. Rapid quantification of soilborne pathogen communities in wheat-based long-term field experiments. Plant Disease 100:1692-1708.

Smiley, R. W., and J. M. Marshall. 2015. Resistance and tolerance of spring wheat and barley to *Heterodera avenae* in the USA. Pages 265-274. In: Nematodes of Small Grain Cereals: Current Status and Research. (A. A. Dababat, H. Muminjanov and R. W. Smiley, editors). FAO, Rome, Italy. 384 pages.

Smiley, R. W., and J. M. Marshall. 2016. Detection of dual *Heterodera avenae* resistance plus tolerance traits in spring wheat. Plant Disease 100:1677-1685.

Smiley, R. W., J. M. Marshall, J. A. Gourlie, T. C. Paulitz, S. L. Kandel, M. O. Pumphrey, K. Garland-Campbell, G. P. Yan, M. D. Anderson, M. D. Flowers, and C. A. Jackson. 2013c. Spring wheat tolerance and resistance to *Heterodera avenae* in Pacific Northwest. Plant Disease 97: 590-600.

Smiley, R. W., K. Merrifield, L.-M. Patterson, R. G. Whittaker, J. A. Gourlie, and S. A. Easley. 2004b. Nematodes in dryland field crops in the semiarid Pacific Northwest USA. Journal of Nematology 36:54-68.

Smiley, R. W., J. M. Marshall, and G. P. Yan. 2011a. Effect of foliarly-applied spirotetramat on reproduction of *Heterodera avenae* on wheat roots. Plant Disease 95:983-989.

Smiley, R. W., and J. M. Nicol. 2009. Nematodes which challenge global wheat production. Pages 171-187. In: Wheat Science and Trade. B.F. Carver (editor). Wiley-Blackwell, Ames, IA. 569 pages.

Smiley, R. W., A. G. Ogg, Jr., and R. J. Cook. 1992b. Influence of glyphosate on severity of Rhizoctonia root rot, growth, and yield of barley. Plant Disease 76:937-942.

Smiley, R. W., and L.-M. Patterson. 1995. Winter wheat yield and profitability from Dividend and Vitavax seed treatment. Journal of Production Agriculture 8:350-354.

Smiley, R. W., and L.-M. Patterson. 1996. Pathogenic fungi associated with Fusarium foot rot of winter wheat in the semiarid Pacific Northwest USA. Plant Disease 80:944- 949.

Smiley, R. W., L.-M. Patterson, and K. E. L. Rhinhart. 1996b. Fungicide seed treatment effects on emergence of deeply planted winter wheat. Journal of Production Agriculture 9:564-570.

Smiley, R. W., L.-M. Patterson, and C. W. Shelton. 1996c. Fungicide seed treatments influence emergence of winter wheat in cold soil. Journal of Production Agriculture 9:559-563.

Smiley, R., T. Paulitz, and J. Marshall. 2012b. Controlling Root and Crown Diseases of Small Grain Crops. PNW Extension Bulletin 639. Oregon State University, Corvallis, OR. 9 pages.

Smiley, R. W., J. G. Sheedy, and S. A. Easley. 2008a. Vertical distribution of *Pratylenchus* spp. in silt loam soil of Pacific Northwest dryland crops. Plant Disease 92:1662-1668.

Smiley, R. W., P. A. Taylor, R. G. Clarke, and F. C. Greenhalgh. 1986b. Simulated soil and plant management effects on root rots of subterranean clover growing in cores of intact soils from pastures. Australian Journal of Agricultural Research 37:633-640.

Smiley, R. W., and D. C. Thompson. 1985. Soil and atmospheric moistures associated with Fusarium crown rot and foliar blight of *Poa pratensis*. Plant Disease 69:294-297.

Smiley, R. W., and W. Uddin. 1993. Influence of soil temperature on Rhizoctonia root rot (*R. solani* AG-8 and *R. oryzae*) of winter wheat. Phytopathology 83:777-785.

Smiley, R. W., W. Uddin, S. Ott, and K. E. L. Rhinhart. 1990a. Influence of flutolanil and tolclofos-methyl on root and culm diseases of winter wheat. Plant Disease 74:788-791.

Smiley, R. W., W. Uddin, P. K. Zwer, D. J. Wysocki, D. A. Ball, T. G. Chastain, and P. E. Rasmussen. 1993b. Influence of crop management practices on physiologic leaf spot of winter wheat. Plant Disease 77:803-810.

Smiley, R. W., R. G. Whittaker, J. A. Gourlie, and S. A. Easley. 2005d. Suppression of wheat growth and yield by *Pratylenchus neglectus* in the Pacific Northwest. Plant Disease 89:958-968.

Smiley, R. W., R. G. Whittaker, J. A. Gourlie, and S. A. Easley. 2005e. *Pratylenchus thornei* associated with reduced wheat yield in Oregon. Journal of Nematology 37:45-54.

Smiley, R. W., R. G. Whittaker, J. A. Gourlie, and S. A. Easley. 2005f. Suppression of wheat growth and yield by *Pratylenchus neglectus* in the Pacific Northwest. Plant Disease 89:958-968.

Smiley, R. W., R. G. Whittaker, J. A. Gourlie, and S. A. Easley. 2006. *Geocenamus brevidens* reduces yield of no-till annual spring wheat in Oregon. Plant Disease 90:885-890.

Smiley, R. W., R. G. Whittaker, J. A. Gourlie, S. A. Easley, and R. E. Ingham. 2005g. Plant-parasitic nematodes associated with reduced wheat yield in Oregon: *Heterodera avenae*. Journal of Nematology 37:297-307.

Smiley, R. W., and D. E. Wilkins. 1992. Impact of sulfonylurea herbicides on Rhizoctonia root rot, growth, and yield of winter wheat. Plant Disease 76:399-404.

Smiley, R. W., and D. E. Wilkins. 1993. Annual spring barley growth, yield and root rot in high- and low-residue tillage systems. Journal of Production Agriculture 6:270-275.

Smiley, R. W., D. E. Wilkins, and S. E. Case. 1991. Barley yields as related to use of seed treatments in eastern Oregon. Journal of Production Agriculture 4:400-407.

Smiley, R. W., D. E. Wilkins, and E. L. Klepper. 1990b. Impact of fungicide seed treatments on Rhizoctonia root rot, take-all, eyespot, and growth of winter wheat. Plant Disease 74:782-787.

Smiley, R. W., and G. P. Yan. 2015a. Discovery of *Heterodera filipjevi* in Washington and comparative virulence with *H. avenae* on spring wheat. Plant Disease 99:376-386.

Smiley, R. W., and G. P. Yan. 2015b. Molecular diagnostics aid in detecting and managing cereal nematodes in the USA. Pages 369-379. In: Nematodes of Small Grain Cereals: Current Status and Research. (A. A. Dababat, H. Muminjanov and R. W. Smiley, editors). FAO, Rome, Italy. 384 pages.

Smiley, R. W., and H. Yan. 2009. Variability of Fusarium crown rot tolerances among cultivars and lines of spring and winter wheat. Plant Disease 93:954-961.

Smiley, R. W., G. P. Yan, and J. A. Gourlie. 2014b. Selected Pacific Northwest rangeland and weed plants as hosts of *Pratylenchus neglectus* and *P. thornei*. Plant Disease 98:1333-1340.

Smiley, R. W., G. P. Yan, and J. A. Gourlie. 2014c. Selected Pacific Northwest crops as hosts of *Pratylenchus neglectus* and *P. thornei*. Plant Disease 98:1341-1348.

Smiley, R. W., G. P. Yan, and Z. A. Handoo. 2008b. First record of the cyst nematode *Heterodera filipjevi* on wheat in Oregon. Plant Disease 92:1136.

Smiley, R. W., G. P. Yan, and J. N. Pinkerton. 2011b. Resistance of wheat, barley and oat to *Heterodera avenae* in the Pacific Northwest USA. Nematology 13:539-552.

Smith, J. D., K. K. Kidwell, M. A. Evans, R. J. Cook, and R. W. Smiley. 2003a. Evaluation of spring cereal grains and wild *Triticum* germplasm for resistance to *Rhizoctonia solani* AG-8. Crop Science 43:701-709.

Smith, J. D., K. K. Kidwell, M. A. Evans, R. J. Cook, and R. W. Smiley. 2003b. Assessment of spring wheat genotypes for disease reaction to *Rhizoctonia solani* AG-8 in controlled environment and direct-seeded field evaluations. Crop Science 43:694-700.

Sojka, E., D.R. Upchurch, D.K. Cassel, K. Olson, B. Payne, S. Petrie, G. Price, H.D. Scott, P. Smethurst, and G. Triplett. 2003. Deficiencies in the soil quality concept and its application. Journal of Soil and Water Conservation 58:180-187.

Solomon, D., J. Lehmann, J. Kinyangi, A. Pell, J. Theis, S. Riha, S. Ngoze, W. Amelung, C. Do Preez, S. Machado, B. Ellert, and H. Janzen. 2009. Anthropogenic and climate influences on biochemical dynamics and molecular-level speciation of sulfur in temperate, subtropical and subhumid tropical ecosystems. Ecological Applications 19:989-1002.

Solomon, D., J. Lehmann, K. K. de Zarruk, J. Dathe, J. Kinyangi, B. Liang, and S. Machado. 2010. Speciation and long- and short-term molecular-level dynamics of soil organic sulfur. Studied by X-ray absorption near-edge structure spectroscopy. Journal of Environmental Quality 40:704-718.

Sprague, R., J. F. Martin, D. E. Stephens, and R. B. Webb. 1937. Dusting Seed Wheat to Control Seed-borne Smut in Oregon. Oregon State Agricultural College, Station Circular of Information 173. 6 pages.

Stanton, T. R., F. A. Coffman, V. F. Tapke, G. A. Wiebe, R. W. Smith, and B. B. Bayles. 1930. Influence of hulling the caryopsis on covered-smut infection and related phenomena in oats. Journal of Agricultural Research 41:621-633.

Stanton, T. R., and D. E. Stephens. 1924. Markton, an Oat Variety Immune from Covered Smut. USDA Dept. Circular 324. 8 pages.

Steiner, J. L., H. H. Schomberg, C. L. Douglas, Jr., and A. L. Black. 1994. Standing stem persistence in no-tillage small grain fields. Agronomy Journal 86:76-81.

Stephens, D. E. 1915. Report of the Eastern Oregon Dry-Farming Branch Experiment Station, Moro, Oregon: 1913-14. Oregon Agricultural College Experiment Station. (no number assigned). 42 pages.

Stephens, D. E. 1917. Experiments with Spring Cereals at the Eastern Oregon Dry-Farming Substation, Moro, Oreg. USDA Bulletin 498. 37 pages.

Stephens, D. E. 1924. Dry-Farm Crop Rotation Experiments at Moro, Oregon. Agricultural Experiment Station Bulletin 209, Oregon Agricultural College and USDA Office of Cereal Investigations, Corvallis. 45 pages.

Stephens, D. E. 1931. Stinking Smut Causes Heavy Losses to Wheat Growers. Oregon State College Agri. Exp. Station Circular of Information 61. 6 pages.

Stephens, D. E. 1944. Effect of tillage and cropping practices on runoff, erosion, and crop yields in the wheat growing areas of Washington, Idaho, and Oregon. Pages 1-105 in D. E. Stephens, Conservation Practices on Wheat Lands of the Pacific Northwest. U.S.D.A. Soil Conservation Service, Pacific Coast Region ·· Seven. Washington, D.C. 125 pages.

Stephens, D. E., and C. E. Hill. 1917. Dry Farming Investigations at the Sherman County Branch Experiment Station. Agricultural Experiment Station Bulletin 144, Oregon Agricultural College, Corvallis. 47 pages.

Stephens, D. E., and G. R. Hyslop. 1922. Wheat Growing after Fallow in Eastern Oregon. Oregon Agricultural College Experiment Station Bulletin 190. 35 pages.

Stephens, D. E., M. A. McCall, and A. F. Bracken. 1923. Experiments in Wheat Production on the Dry Lands of the Western United States. USDA Department Bulletin No. 1173. US Government Printing Office, Washington, D.C. 60 pages.

Stephens, D. E., G. A. Mitchell, M. M. Oveson, and J. Belanger. 1941. Methods of disposal of crop residues for growing wheat after fallow in eastern Oregon. A 20-page addendum in D.E. Stephens. 1944. Conservation Practices on Wheat Lands of the Pacific Northwest. U.S.D.A. Soil Conservation Service, Pacific Coast Region ·· Seven. Washington, D.C. 125 pages.

Stephens, D. E., M. M. Oveson, and G. A. Mitchell. 1943. Water Requirement of Wheat at the Sherman Branch Experiment Station. Agricultural Experiment Station Technical Bulletin 1, Oregon State College, Corvallis. 27 pages.

Stephens, D. E., H. M. Wanser, and A. F. Bracken. 1932a. Experiments in Wheat Production on the Dry Lands of Oregon, Washington, and Utah. USDA Technical Bulletin 329. 68 pages.

Stephens, D. E., R. B. Webb, and J. F. Martin. 1932b. Wheat Varieties for the Columbia River Basin of Oregon. Agricultural Experiment Station Bulletin 308. Oregon State Agricultural College, Corvallis. 37 pages.

Stephens, D. E., R. Withycombe, and O. Shattuck. 1924. Spring Crops for Eastern Oregon. Agricultural Experiment Station Bulletin 204, Oregon Agricultural College, Corvallis. 36 pages.

Stephens, D. E., and H. M. Woolman. 1922. The Wheat Bunt Problem in Oregon. Agricultural Experiment Station Bulletin 188, Oregon Agricultural College and USDA Office of Cereal Investigations, Corvallis. 42 pages.

Stevens, J. F., R. L. Reed, S. Alber, L. Pritchett, and S. Machado. 2009. Herbicidal activity of glucosinolate degradation products in fermented meadowfoam (*Limnanthes alba*) seed meal. Journal of Agricultural and Food Chemistry 57:1821-1826.

Strauss, S. L., C. L. Reardon, and M. Mazzola. 2014. The response of ammonia-oxidizer activity and community structure to fertilizer amendment of orchard soils. Soil Biology and Biochemistry 68:410-418.

Subbarao, G. V., C. R. Renard, W. A. Payne, and A. B. Bationo. 2000. Long-term effects of tillage, phosphorus fertilization and crop rotation on pearl millet-cowpea productivity in the West-African Sahel. Experimental Agriculture 36:243-264.

Sulik, J., and D. Long. 2015. Spectral indices for yellow canola flowers. International Journal of Remote Sensing 36:2751-2756.

Sulik, J., and D. Long. 2016. Spectral considerations for modeling yield of canola. Remote Sensing of Environment 184:161-174.

Sulik, J., N. Newlands, and D. Long. 2017. Encoding dependence in Bayesian causal networks. Frontiers in Environmental Science 4:84. doi:10.3389/fenvs.2016.00084.

Sullivan, D. M., D. A. Horneck, and D. J. Wysocki. 2013. Eastern Oregon Liming Guide. Oregon State University Extension Service Memo EM 9060, Corvallis, OR. 12 pages.

Sullivan, L. S., F. L. Young, R. W. Smiley, and J. R. Alldredge. 2013. Weed and disease incidence in no-till facultative wheat in the Pacific Northwest, USA. Crop Protection 53:132-138.

Swan, D. G., and C. R. Rohde, 1962. Effect of 2,4-D on three winter wheat varieties grown in Oregon. Crop Science 2:179-180.

Swan, D. G., and W. R. Furtick, 1962. Competition of fiddleneck with wheat. Weeds 10:121-123.

Tao, H., G. Yorgey, D. Huggins, and D. Wysocki. 2017. Crop residue management. Pages 125-162. In: Advances in Dryland Farming in the Inland Pacific Northwest (G. Yorgey and C. Kruger, editors). Washington State Universtiy, Pullman, WA. 614 pages.

Tarasoff, C. S, D. A. Ball, and C. A. Mallory-Smith. 2007a. Afterripening requirements and optimal germination temperatures for Nuttall's alkali grass and weeping alkaligrass. Weed Science 55:36-40.

Tarasoff, C. S., D. A. Ball, and C. Mallory-Smith. 2007b. Comparative plant responses of *Puccinellia nuttalliana* and *Puccinellia distans* to sodic versus normal soil types. Journal of Arid Environments 70:403-417.

Tarasoff, C. S., D. A. Ball, and C. Mallory-Smith. 2007c. Extreme ionic and temperature effects on germination of weeping alkaligrass, Nuttall's alkaligrass and Kentucky bluegrass. Weed Science 55:305–310.

Tarasoff, C. S., D. A. Ball, C. Mallory-Smith, T. G. Pypker, and K. M. Irvine. 2010. Site characteristics associated with Nuttall's and weeping alkaligrass in northeastern Oregon. Northwest Science 84:351-360.

Tarasoff, C. S., M. Louhaichi, C. A. Mallory-Smith, and D. A. Ball. 2005. Using geographic information systems to present non geographical data - an example using a two-way thermogradient plate. Rangeland Ecology and Management 58:315-318.

Tarasoff, C. S., C. Mallory-Smith, and D. A. Ball. 2009. Competitive effects of Nuttall's and weeping alkaligrass in Kentucky bluegrass. Northwest Science 83:325-333.

Tautges, N. E., T. S. Sullivan, C. L. Reardon, and I. C. Burke. 2016. Soil microbial diversity and activity linked to crop yield and quality in a dryland organic wheat production system. Applied Soil Ecology 108: 258-268.

Taylor, H. M., and B. Klepper. 1978. The role of rooting characteristics in the supply of water to plants. Advances in Agronomy 30:99-128.

Taylor, H. M., B. Klepper, and R. W. Rickman. 1979. Some problems in modeling root water uptake. American Society of Agricultural Engineers Paper No. 79-4516.

Taylor, P. A., R. G. Clarke, K. Kelley, and R. W. Smiley. 1985. Root rot of irrigated subterranean clover in northern Victoria: Significance and prospects for control. Pages 271-273. In: Ecology and Management of Soilborne Plant Pathogens (C. A. Parker, A. D. Rovira, K. J. Moore, and P. T. W. Wong, editors). American Phytopathological Society, St. Paul, MN. 358 pages.

Terman, G. L., R. E. Ramig, A. F. Drier, and R. A. Olson. 1969. Yield-protein relationships in wheat grain, as affected by nitrogen and water. Agronomy Journal 61:755-759.

Thompson, A. L., A. K. Mahoney, R. W. Smiley, T. C. Paulitz, S. Hulbert, and K. Garland-Campbell. 2017. Resistance to multiple soil-borne pathogens of the Pacific Northwest is co-located in a wheat recombinant inbred line population. G3 (Genes, Genomes, Genetics) 7:1109-1116.

Thompson, A. L., R. W. Smiley, and K. Garland-Campbell. 2015. Registration of the 'LouAu' (Louise/IWA8608077) wheat recombinant inbred line mapping population. Journal of Plant Registrations 9: 424-429.

Thompson, A. L., R. W. Smiley, T. C. Paulitz, and K. Garland-Campbell. 2016. Identification of resistance to *Pratylenchus neglectus* and *Pratylenchus thornei* in Iranian landrace accessions of wheat. Crop Science 56:654-672.

Tisdale, W. H., J. E. Martin, F. N. Briggs, W. W. Mackie, H. M. Woolman, D. E. Stephens, E. F. Gaines, and F. J. Stevenson. 1925. Relative Resistance of Wheat to Bunt in the Pacific Coast States. USDA Department Bulletin No. 1299. US Government Printing Office, Washington, D.C. 29 pages.

Uddin, W., and T. R. Knous. 1991. *Fusarium* species associated with crown rot of alfalfa in Nevada. Plant Disease 75:51-56.

Vahabian, M. A., and W. E. Kronstad. 1983. Effects of seed source and seed size on stand establishment, grain yield and yield components of seven wheat cultivars grown under three diverse environments. Pages 1171-1177. In: Proceedings of 6th International Wheat Genetics Symposium, Sadao Sakamoto (editor). Plant Germ-Plasm Institute, Kyoto University, Kyoto, Japan.

Van Doren, D. M., Jr., and R. R. Allmaras. 1978. Effect of residue management practices on the soil physical environment, micro-climate, and plant growth. Pages 48-83. In: Crop Residue Management Systems (W. R Oschwald, editor). American Society of Agronomy Special Publication 31, Madison, WI. 248 pages.

Veseth, R., B. Miller, S. Guy, D. Wysocki, T. Murray, R. Smiley, and M. Wiese. 1993. Managing Cephalosporium stripe in conservation tillage systems. PNW Conservation Tillage Handbook. Series 4:17. Pullman, WA. 8 pages.

Veseth, R., A. Ogg, D. Thill, D. A. Ball, D. J. Wysocki, F. Bailey, T. Gohlke, and H. Riehle. 1994. Managing Downy Brome under Conservation Tillage Systems in the Inland Northwest Crop-Fallow Region. Chapter 5. No. 15. In: Pacific Northwest Conservation Tillage Handbook Series. 8 pages.

Veseth, R., and D. J. Wysocki. 1989. Pacific Northwest Conservation Tillage Handbook. PNW Extension Publication, University of Idaho, Moscow, ID. 180 pages.

Villas-Boas, P. R., M. A. Franco, L. Martin-Neto, H. T. Gollany, and D. M. B. P. Milori. 2019. Applications of laser-induced breakdown spectroscopy for soil analysis, part I: Review of fundamentals and chemical and physical properties. European Journal of Soil Science 2019:1-16. (on-line at https://doi.org/10.1111/ejss.12888).

Villas-Boas, P. R., M. A. Franco, H. T. Gollany, L. Martin-Neto, and D. M. B. P. Milori. 2019. Applications of laser-induced breakdown spectroscopy for soil analysis, part II: Review of elemental analysis and soil classification. European Journal of Soil Science (in press; doi: 10.1111/ejss.12889).

Vogel, O. A. 1957a. Burt, A Hard White Winter Wheat. Oregon Agricultural Experiment Station Circular of Information 581. 4 pages.

Vogel, O. A. 1957b. Omar, A Red-Chaffed White Club Wheat. Oregon Agricultural Experiment Station Circular of Information 568. 4 pages.

Vogel, O. A., J. C. Craddock Jr., C. E. Muir, E. H. Everson, and C. R. Rohde. 1956. Semidwarf growth habit in winter wheat improvement for the Pacific Northwest. Agronomy Journal 48:76-78.

Vomocil, J. A, J. L. Pikul, Jr., J. F. Zuzel, and D. Baldwin. 1984. Stubble management influences soils freezing. Oregon State University Extension Service Special Report 700.

Vomocil, J. A., and R. E. Ramig. 1976. Wind erosion control on irrigated Columbia Basin land: A handbook of practices. Oregon State University Extension Service Special Report 466. 24 pages.

Vomocil, J. A., and R. E. Ramig. 1984. Annual cropping on shallow soils. Oregon State University Extension Service Special Report 701.

Voorhees, W. B., R. R. Allmaras, and C. E. Johnson. 1981. Alleviating temperature stress. Pages 217-266. In: Modifying the Root Environment to Reduce Crop Stress (G. F. Arkin and H. M. Taylor, editors). ASAE Monograph No.4. American Society of Agricultural Engineers, St. Joseph, MI. 407 pages.

Voorhees, W. B., Min Amemiya, R. R. Allmaras, and W. E. Larson. 1971. Some effects of aggregate structure heterogeneity on root growth. Soil Science Society of America Proceedings 35:638-643.

Waddoups, H. M. 1956. Progress report ... possible new dryland crops in Umatilla County. Oregon Agricultural Experiment Station Circular of Information 561. 8 pages.

Waldman, S. E., and R. W. Rickman. 1990. Programming techniques to expedite communication of scientific models. Agronomy Journal 82:356-359.

Waldman, S. E., and R. W. Rickman. 1996. MODCROP: A crop simulation framework. Agronomy Journal 88:170-175.

Walenta, D. L., J. P. Yenish, F. L. Young, and D. A. Ball. 2002. Vernalization response of plants grown from spikelets of spring and fall cohorts of jointed goatgrass. Weed Science 50:461-465.

Wan, C. G., W. Xu, R. E Sosebee, S. Machado, and T. Archer. 2000. Hydraulic lift in drought-tolerant and susceptible corn hybrids. Plant and Soil 219:117-126.

Ward, K. I., B. Klepper, R. W. Rickman, and R. R. Allmaras. 1978. Quantitative estimation of living wheat root lengths in soil cores. Agronomy Journal 70:675-677.

Warn, W. R, R. R. Allmaras, G. A. Muilenburg, and J. F. Zuzel. 1981. A portable device for installing lightweight borders for runoff and erosion plots. Soil Science Society of America Journal 45:664-666.

Washburn, R. S. and H. D. Scudder. 1927. Cost of Producing Winter Wheat and Incomes from Wheat Farming in Sherman County, Oreg. USDA Department Bulletin No. 1446. US Government Printing Office, Washington, D.C. 40 pages.

Washburn, R. S., and H. D. Scudder. 1926. Cost of Using Horses, Tractors and Combines on Wheat Farms in Sherman County, Oreg. USDA Department Bulletin No. 1447. US Government Printing Office, Washington, D.C. 45 pages.

Weerakoon, D. M. N., C. L. Reardon, T. C. Paulitz, A. D. Izzo, and M. Mazzola. 2012. Long-term suppression of *Pythium abappressorium* induced by *Brassica juncea* seed meal amendment is biologically mediated. Soil Biology and Biochemistry 51:44-52.

Whitson, T. D., D. Cudney, R. Parker, D. A. Ball, S. A. Dewey, C. L. Elmore, R. G. Lym, D. W. Morishita, D. G. Swan, and R. K. Zollinger. 2009. Weeds of the West, 10th edition. Western Soc. of Weed Science. Las Cruces, NM. 626 pages.

Wienhold, B. J., M. R. Schmer, V. L. Jin, G. E. Varvel, and H. T. Gollany. 2016. CQESTR simulated changes in soil organic carbon under residue management practices in continuous corn systems. Bioenergy Research 9:23–30.

Wilhelm, W. W., J. R. Hess, D. L. Karlen, J. M. F. Johnson, D. J. Muth, J. M. Baker, H. T. Gollany, J. M. Novak, D. E. Stott, and G. E. Varvel. 2010. Balancing limiting factors and economic drivers for sustainable midwestern US agricultural residue feedstock supplies. Industrial Biotechnology 6:271-287.

Wilhelm, W. W., G. S. McMaster, B. Klepper, and R. W. Rickman. 1990. A vegetative development and growth model for wheat. Pages 34-35. In: Climatic Risk in Crop Production: Models and Management for the Semi-arid Tropics and Subtropics (R. C. Muchow and J. A. Bellamy, editors). CAB International, Wallingford, UK. 305 pages.

Wilhelm, W. W., G. S. McMaster, R. W. Rickman, and B. Klepper. 1993. Above-ground vegetative development and growth of winter wheat as influenced by nitrogen and water availability. Ecological Modelling 68:183-203.

Wilkins, D. E. 1988. Apparatus for placement of fertilizer below seed with minimum soil disturbance. U.S. Patent number 4,765,263.

Wilkins, D. E. 1996. Tillage, seeding and fertilizer application technologies. American Journal of Alternative Agriculture 11:83-88.

Wilkins, D. E., P. A. Adrian, and W. J. Conley. 1979. Punch planting of vegetable seeds – A progress report. Transactions of the American Society of Agricultural Engineers 22:746-749.

Wilkins, D. E., R. R. Allmaras, J. M. Kraft, and R. E. Ramig. 1985. Machinery systems for pea and winter wheat production in the Pacific Northwest. In: Proceedings of the International Conference on Soil Dynamics 3:582-591. Auburn, AL.

Wilkins, D., F. Bolton, and K. Saxton. 1992a. Evaluating seeders for conservation tillage production of peas. Applied Engineering in Agriculture 8:165-170.

Wilkins, D. E., and W. I. Conley. 1981. Apparatus for planting seeds. United States Patent No. 4,300,462.

Wilkins, D. E., C. L, Douglas, Jr., and D. B. Churchill. 1993. Soft white winter wheat kernel separation by percent protein. Transactions of the American Society of Agricultural Engineers 36:1841-1845.

Wilkins, D. E., C. L. Douglas, Jr., and J. L. Pikul, Jr. 1996. Header loss for Shelbourne Reynolds stripper-header harvesting wheat. Applied Engineering in Agriculture 12:159-162.

Wilkins, D. E., C. L. Douglas, Jr., P. E. Rasmussen, and D. A. Haasch. 1983a. Tillage influences on residue incorporation and soil moisture. American Society of Agricultural Engineers Paper No. 83-1026.

Wilkins, D. E., C. L. Douglas, Jr., and R. W. Smiley. 1992b. Influence of tillage and seed on wheat disease. American Society of Agricultural Engineers Paper 92-1591.

Wilkins, D. E., E. A. Dowding, G. M. Hyde, C. L. Peterson, and G. J. Swanson. 1987. Conservation tillage equipment for seeding. Pages 571-575. In: STEEP-Conservation Concepts and Accomplishments (L. F. Elliott, editor). Washington State University, Pullman, WA.

Wilkins, D. E., D. A. Haasch, P. E. Rasmussen, and J. M. Kraft. 1984a. Chisel planting effects on pea growth. American Society of Agricultural Engineers Paper No. 84-1011.

Wilkins, D. E., M. R. Haferkamp, and D. C. Ganskopp. 1990. Power requirements of an imprinter and rangeland drill. Journal of Range Management 43:273-274.

Wilkins, D. E., B. Klepper, and P. E. Rasmussen. 1984b. Grain stubble effect on winter wheat seedling development. American Society of Agricultural Engineers Paper No. 84-1514.

Wilkins, D. E., B. Klepper, and R. W. Rickman. 1982a. Effect of tillage on wheat tillering. American Society of Agricultural Engineers Paper No. 82-1512.

Wilkins, D. E., B. Klepper, and R. W. Rickman. 1989. Measuring wheat seedling response to tillage and seeding systems. Transactions of the American Society of Agricultural Engineers 32:795-800.

Wilkins, D. E., B. L. Klepper, and P. E. Rasmussen. 1988a. Management of grain stubble for conservation tillage systems. Soil and Tillage Research 12:25-35.

Wilkins, D. E., and J. M. Kraft. 1987. Crop residue management and pea root rot disease. American Society of Agricultural Engineers Paper No. 87-2510.

Wilkins, D. E., and J. M. Kraft. 1988. Managing crop residue and tillage pans for pea production. Pages 927-932. In: Proceedings of the International Soil and Tillage Research Organization. Edinburgh, Scotland.

Wilkins, D. E., J. M. Kraft, and B. L. Klepper. 1988b. Influence of plant spacing on pea yield. American Society of Agricultural Engineers Paper No. 88-1567.

Wilkins, D. E., J. M. Kraft, and B. L. Klepper. 1991a. Influence of plant spacing on pea yield. Transactions of the American Society of Agricultural Engineers 34:1957-1961.

Wilkins, D. E., and D. H. Lenker. 1981. A microprocessor-controlled planter. Transactions of the American Society of Agricultural Engineers 24:2-4, 8.

Wilkins, D. E., G. A. Muilenburg, R. R. Allmaras, and C. E. Johnson. 1981. Effect of grain drill opener on wheat emergence. American Society of Agricultural Engineers Paper No. 81-1021.

Wilkins, D. E., G. A. Muilenburg, R. R. Allmaras, and C. E. Johnson. 1983b. Grain-drill opener effects on wheat emergence. Transactions of the American Society of Agricultural Engineers 26:651-655, 660.

Wilkins, D. E., and J. L. Pikul, Jr. 1992. Soil physical properties. Pages 180-186. In: Methods for Research on Soilborne Phytopathogenic Fungi (L. L. Singleton, J. D. Mihail, and C. M. Rush, editors). APS Press, St. Paul, MN. 266 pages.

Wilkins, D. E., P. E. Rasmussen, B. Klepper, and D. A. Haasch. 1982b. Grain drill opener design for fertilizer placement. American Society of Agricultural Engineers Paper No. 82-1516.

Wilkins, D. E., P. E. Rasmussen, and J. M. Kraft. 1986. Effect of paraplowing on wheat and fresh pea yields. American Society of Agricultural Engineers Paper No. 86-1516.

Wilkins, D. E, M. C. Siemens, and S. L. Albrecht. 2002. Changes in soil physical characteristics during transition from intensive tillage to direct seeding. Transactions of the American Society of Agricultural Engineers 45:877-880.

Wilkins, D. E., J. F. Zuzel, J. L. Pikul, Jr., and R. W. Smiley. 1991b. Tillage tool for enhancing water infiltration through frozen soil. Pages 393-398. In: Preferential Flow (T. J. Gish and A. Shirmohammadi, editors). American Society of Agricultural Engineers, St. Joseph, MI. 408 pages.

Williams, J. D. 2004. Effects of long-term winter wheat, summer fallow residue and nutrient management on field hydrology for a silt loam in north-central Oregon. Soil and Tillage Research 75:109-119.

Williams, J. D. 2008. Soil erosion from dryland winter wheat-fallow in a long-term residue and nutrient management experiment in north-central Oregon. Journal Soil and Water Conservation 63:53-59.

Williams, J. D., S. L. Albrecht, R. W. Rickman, C. L. Douglas, Jr., C. L. Reardon, and D. K. McCool. 2013. Root to shoot ratios and belowground biomass distribution for Pacific Northwest dryland crops. Journal of Soil and Water Conservation 68:349-360.

Williams, J. D., and J. C. Buckhouse. 1991. Surface runoff plot design for use in watershed research. Journal of Range Management 44:411-412.

Williams, J. D., and J. C. Buckhouse. 1993. Winter logging and erosion in a ponderosa pine forest in northeastern Oregon. Western Journal of Applied Forestry 8:19-23.

Williams, J. D., J. P. Dobrowolski, D. A. Gillette, and N. E. West. 1995a. Microphytic crust influence on wind erosion. Transactions of the American Society of Agricultural Engineers 38:131-137.

Williams, J. D., J. P. Dobrowolski, and N. E. West. 1995b. Microphytic crust influence on interrill erosion and infiltration capacity. Transactions American Society Agricultural Engineers 38:139-146.

Williams, J. D., J. P. Dobrowolski, and N. E. West. 1999. Microbiotic crust influence on unsaturated hydraulic conductivity. Arid Soil Research and Rehabilitation 13:145-154.

Williams, J. D., S. Dun, D. S. Robertson, J. Q. Wu, E. Brooks, D. C. Flanagan, and D. K. McCool. 2010. WEPP simulations of runoff events from small drainages on the northeastern Oregon. Journal of Soil and Water Conservation 65:22-33.

Williams, J. D., H. T. Gollany, M. C. Siemens, S. B. Wuest, and D. S. Long. 2009. Comparison of runoff, soil erosion, and winter wheat yields from no-till and inversion tillage production systems in northeastern Oregon. Journal of Soil and Water Conservation 64:43-52.

Williams, J. D., H. M. Hartman, L. M. Spencer, and J. O. Loiland. 2011a. Vegetation development in a dryland CREP in northeastern Oregon. American Journal of Plant Sciences 2:744-752.

Williams, J. D., and D. W. Kolpin. 2005. Current topics in agricultural hydrology and water quality: introduction. Journal of the American Water Resources Association 41:243-244.

Williams, J. D., and D. S. Long. 2011. Intensive crop rotation yield and economic performance compared in minimum tillage and no-tillage, N.E. Oregon. Crop Management online at doi: 10.1094/CM-2011-0328-01-RS.

Williams, J. D., D. S. Long, and S. B. Wuest. 2011b. Capture of plateau runoff by global positioning system-guided drill seed operation. Journal of Soil and Water Conservation 66:355-361.

Williams, J. D., D. K. McCool, C. L. Reardon, C. L. Douglas, Jr., S. L. Albrecht, and R. W. Rickman. 2013. Root:shoot ratios and belowground biomass distribution for Pacific Northwest dryland crops. Journal of Soil and Water Conservation 68:349-360.

Williams, J. D., C. Reardon, S. B. Wuest, and D. Long. 2018. Soil wet aggregate stability in dryland Pacific Northwest intensified crop rotations. Soil Science Society of America Journal 82:455-462.

Williams, J. D., and D. S. Robertson. 2016. Soil water in small drainages farmed with no-tillage and inversion tillage in northeastern Oregon. Journal of Soil and Water Conservation 71:503-511.

Williams, J. D., D. S. Robertson, D. S. Long, S. B. Wuest, D. Kumar, A. Juneja, and G. S. Murthy. 2016. Ethanol production potential from conservation buffers in the inland Pacific Northwest. Journal of Renewable and Sustainable Energy 8(5):053102.

Williams, J. D., D. S. Robertson, and S. B. Wuest. 2015a. Biofuel feedstock production potential in stream buffers of the inland Pacific Northwest: Productivity and management issues with invasive plants. Journal of Soil and Water Conservation 70:156-169.

Williams, J. D., D. E. Wilkins, C. L. Douglas, Jr., and R. W. Rickman. 2000. Mow-plow crop residue management influence on soil erosion in north-central Oregon. Soil and Tillage Research 55:71-78.

Williams, J. D., D. E. Wilkins, D. K. McCool, L. L. Baarstad, B. L. Klepper, and R. I. Papendick. 1998. A new rainfall simulator for use in low–energy rainfall areas. Applied Engineering in Agriculture 14:243–247.

Williams, J. D., and S. B. Wuest. 2011. Tillage and no-tillage conservation effectiveness in the intermediate precipitation zone of the inland Pacific Northwest, United States. Journal of Soil and Water Conservation 66:242-249.

Williams, J. D., and S. B. Wuest. 2014. Soil water dynamics in continuous winter wheat grown in the semiarid Pacific Northwest, U.S.A. Soil Science Society of America Journal 78:571-578.

Williams, J. D., S. B. Wuest, and D. S. Long. 2014. Soil and water conservation in the Pacific Northwest through no-tillage and intensified crop rotations. Journal of Soil and Water Conservation 69:495-504.

Williams J. D., S. B. Wuest, and D. S. Robertson. 2015. Soil water and water-use efficiency in no-tillage and sweep tillage winter wheat production in northeastern Oregon. Soil Science Society of America Journal 79:1206-1212.

Williams. J. D., S. B. Wuest, W. F. Schillinger, and H. T. Gollany. 2006. Rotary subsoiling newly planted winter wheat fields to improve infiltration in frozen soil. Soil and Tillage Research 86:141-151.

Winkle, T., J. F. Renno, and W. A. Payne. 1997. Effect of the timing of water deficit on growth, phenology and yield of pearl millet (*Pennisetum glaucum* (L.) R. Br.) grown in Sahelian conditions. Journal of Experimental Botany 48:1001-1009.

Woolman, H. M. 1914. Stinking smut of wheat. Washington Agricultural Experiment Station Popular Bulletin No. 73. 8 pages.

Woolman, H. M., and H. B. Humphrey. 1924. Summary of the literature on bunt or stinking smut of wheat. U. S. Department of Agriculture Bulletin No. 1210. 44 pages.

Wuest, S. 2007. Vapour is the principal source of water imbibed by seeds in unsaturated soils. Seed Science Research 17:3-9.

Wuest, S. B. 2001a. Earthworm, infiltration, and tillage relationships in a dryland pea-wheat rotation. Applied Soil Ecology 18:187-192.

Wuest, S. B. 2001b. Soil biopore estimation: Effects of tillage, nitrogen, and photographic resolution. Soil and Tillage Research 62:111-116.

Wuest, S. B. 2002. Water transfer from soil to seed: The role of vapor transport. Soil Science Society of America Journal 66: 1760-1763.

Wuest, S. B. 2005. Bias in ponded infiltration estimates due to sample volume and shape. Vadose Zone Journal 4:1183-1190.

Wuest, S. B. 2007. Surface versus incorporated residue effects on water-stable aggregates. Soil and Tillage Research 96:124-130.

Wuest, S. B. 2009a. Comparison of preferential flow paths to bulk soil in a weakly aggregated silt loam soil. Vadose Zone Journal 8:623-627.

Wuest, S. B. 2009b. Correction of bulk density and sampling method biases using soil mass per unit area. Soil Science Society of America Journal 73:312-316.

Wuest, S. B. 2009c. How tillage affects water infiltration. Oregon Soil Quality Technical Note No. 3. USDA Natural Resources Conservation Service, Portland OR.

Wuest, S. B. 2010. Tillage depth and timing effects on soil water profiles in two semi-arid soils. Soil Science Society of America Journal 74:1701-1711.

Wuest, S. B. 2013. An array for measuring detailed soil temperature profiles. Soil Science Society of America Journal 77:427-431.

Wuest, S. B. 2014. Seasonal variation in soil organic carbon. Soil Science Society of America Journal 78:1442-1447.

Wuest, S. B. 2015. Seasonal variation in soil bulk density, organic nitrogen, available phosphorus, and pH. Soil Science Society of America Journal 79:1188-1197.

Wuest, S. B. 2017. Surface effects on water storage under dryland summer fallow, a lysimeter study. Vadose Zone Journal 17: doi:10.2136/vzj2016.09.0078.

Wuest, S. B., S. L. Albrecht, and K. W. Skirvin. 1999a. Vapor transport vs. seed-soil contact in wheat germination. Agronomy Journal 91:783-787.

Wuest, S. B., S. L. Albrecht, and K. W. Skirvin. 2000. Crop residue position and interference with wheat seedling development. Soil and Tillage Research 55:175-182.

Wuest, S. B., and J. Barroso. 2019. Is volunteer wheat a serious weed in annual winter wheat production? Crop Protection: (in press)

Wuest, S. B., T. Caesar-TonThat, S. F. Wright, and J. D. Williams. 2005. Organic matter additions, N, and residue burning effects on infiltration, biological, and physical properties of an intensively tilled silt-loam soil. Soil and Tillage Research 84:154-167.

Wuest, S. B., and M. K. Corp. 2011. One-pass tillage for summer fallow under arid summer conditions. Crop Management. Online at doi: 10.1094/CM-2011-1223-03-RS.

Wuest, S. B., D. Durr, and S. L. Albrecht. 2003. Carbon dioxide flux measurement during simulated tillage. Agronomy Journal 95:715-718.

Wuest, S. B., and H. T. Gollany. 2013. Soil organic carbon and nitrogen after application of nine organic amendments. Soil Science Society of America Journal 77:237-245.

Wuest, S. B., R. S. Karow, R. J. Veseth, D. J. Wysocki, B. C. Miller, J. R. Alldredge, and S. O. Guy. 1994. Increasing plot length reduces experimental error of on-farm tests. Journal of Production Agriculture 7:211-215.

Wuest, S. B., and L. K. Lutcher. 2013. Soil water potential requirement for germination of winter wheat. Soil Science Society of America Journal 77:279-283.

Wuest, S. B., D. K. McCool, B. C. Miller, and R. J. Veseth. 1999b. Development of more effective conservation farming systems through participatory on-farm research. American Journal of Alternative Agriculture 14:98-102.

Wuest, S. B., and C. L. Reardon. 2016. Surface and root inputs produce different carbon/phosphorus ratios in soil. Soil Science Society of America Journal 80:463-471.

Wuest, S. B., and W. F. Schillinger. 2008. Small-increment electric soil sampler. Soil Science Society of America Journal 72:1554-1556.

Wuest, S. B., and W. F. Schillinger. 2011. Evaporation from high residue no-till versus tilled fallow in a dry summer climate. Soil Science Society of America Journal 75:1512-1518.

Wuest, S. B., and W. F. Schillinger. 2019. Soil water dynamics with spring camelina in a three-year rotation in Washington's winter wheat-fallow region. Soil Science Society of America Journal 83:1525-1532.

Wuest, S. B., J. D. Williams, and H. T. Gollany. 2006. Tillage and perennial grass effects on ponded infiltration for seven semi-loess soils. Journal of Soil and Water Conservation 61:218-223.

Wysocki, D. J., T. G. Chastain, W. S. Schillinger, S. O. Guy, and R. S. Karow. 2013a. Camelina: Seed yield response to applied nitrogen and sulfur. Field Crops Research 145:60-66.

Wysocki, D. J., and M. K. Corp. 2013. Dryland cropping systems: Edible mustard. Oregon State University Extension Service Bulletin 8796. 6 pages.

Wysocki, D. J., M. K. Corp, D. A. Horneck, and L. Lutcher. 2013b. Irrigated and dryland canola nutrient management guide. Oregon State University Extension Service Fertilizer Guide EM8943. Corvallis, OR. 8 pages.

Wysocki, D. J., L. K. Lutcher, D. A. Horneck, J. M. Hart, and S. E. Petrie. 2005a. Winter wheat and spring grains in continuous cropping systems-low precipitation zone. Oregon State University Extension Service Fertilizer Guide FG81-E. Corvallis, OR. 8 pages.

Wysocki, D. J., L. K. Lutcher, D. A. Horneck, J. M. Hart, and S. E. Petrie. 2012. Winter wheat and spring grains in continuous cropping systems (low precipitation zone) fertilizer guide. Oregon State University Extension Service Fertilizer Guide FG81. Corvallis, OR. 8 pages.

Wysocki, D. J., L. K. Lutcher, D. A. Horneck, J. M. Hart, S. E. Petrie, and M. K. Corp. 2005b. Winter wheat in continuous cropping systems-intermediate precipitation zone. Oregon State University Extension Service Fertilizer Guide FG83-E. Corvallis, OR. 8 pages.

Wysocki, D. J., L. K. Lutcher, D. A. Horneck, J. M. Hart, S. E. Petrie, and M. K. Corp. 2007. Winter wheat in continuous cropping systems - intermediate precipitation zone. Oregon State University Extension Service Fertilizer Guide FG83-E. Corvallis, OR. 8 pages.

Wysocki, D. J., P. E. Rasmussen, F. L. Young, R. J. Cook, D. L. Young, and R. I. Papendick. 1995a. Achieving conservation compliance with residue farming in the low-precipitation zone. Pages 32-34. In: Crop Residue Management to Reduce Erosion and Improve Soil Quality - Northwest (R. I. Papendick and W. C. Moldenhauer, editors). Conservation Report No. 40. USDA-ARS, Washington, D.C. 76 pages.

Wysocki, D. J., F. L. Young, R. J. Cook, P. E. Rasmussen, D. L. Young, R. J. Veseth, and R. I. Papendick. 1995b. Achieving conservation compliance with residue farming in the intermediate-precipitation zone. Pages 26-3l. In: Crop Residue Management to Reduce Erosion and Improve Soil Quality - Northwest (R. I. Papendick and W. C. Moldenhauer, editors). Conservation Report No. 40. USDA-ARS, Washington, D.C. 76 pages.

Yan, G. P., and R. W. Smiley. 2009. Discovery of *Heterodera filipjevi* on wheat in the USA. Pages 94-99. In: Cereal Cyst Nematodes: Status, Research and Outlook. (I. T. Riley, J. M. Nicol, and A. A. Dababat, editors). CIMMYT, Ankara, Turkey. 244 pages.

Yan, G. P., and R. W. Smiley. 2010. Distinguishing *Heterodera filipjevi* and *H. avenae* using polymerase chain reaction-restriction fragment length polymorphism and cyst morphology. Phytopathology 100:216-224.

Yan, G. P., R. W. Smiley, and P. A. Okubara. 2012. Detection and quantification of *Pratylenchus thornei* in DNA extracted from soil using real-time PCR. Phytopathology 102:14-22.

Yan, G. P., R. W. Smiley, P. A. Okubara, and A. M. Skantar. 2013a. Species-specific PCR assays for differentiating *Heterodera filipjevi* and *H. avenae*. Plant Disease 97:1611-1619.

Yan, G. P., R. W. Smiley, P. A. Okubara, A. Skantar, S. A. Easley, J. G. Sheedy, and A. L. Thompson. 2008. Detection and discrimination of *Pratylenchus neglectus* and *P. thornei* in DNA extracts from soil. Plant Disease 92:1480-1487.

Yan, G. P., R. W. Smiley, P. A. Okubara, A. M. Skantar, and C. L. Reardon. 2013b. Developing a real-time PCR assay for detection and quantification of *Pratylenchus neglectus* in soil. Plant Disease 97:757-764.

Yenish, J. P., D. A. Ball, and R. Schirman. 2009. Integrated Management of Jointed Goatgrass in the Pacific Northwest. Washington State University Extension Bulletin EB2042. 16 pages.

Yenish, J., R. Veseth, A. Ogg, D. Thill, D. Ball, F. Young E. Gallandt, D. Morishita, C. Mallory-Smith, D. Wysocki, T. Gohlke. 1998. Managing Downy Brome under Conservation Tillage Systems in the Inland Northwest Crop-Fallow Region. Pacific Northwest Extension Publication PNW 0509. 15 pages.

Yin, C., L. McLaughin, T. Paulitz, D. R. Kroese, and C. H. Hagerty. 2020. Population dynamics of wheat root pathogens under different tillage systems in NE Oregon. *Plant Disease* (in press).

Yorgey, G., W. Pan, R. Awale, S. Machado, and A. Bary. 2017. Soil amendments. Pages 283-318. In: Advances in Dryland Farming in the Inland Pacific Northwest (G. Yorgey and C. Kruger, editors). Washington State Universtiy, Pullman, WA. 614 pages.

Young, F. L., D. A. Ball, D. C. Thill, J. R. Alldredge, A. G. Ogg, Jr., and S. S. Seefeldt. 2010. Integrated weed management systems identified for jointed goatgrass (*Aegilops cylindrica*) in the Pacific Northwest. Weed Technology 24:430-439.

Young, F. L., J. P. Yenish, D. L. Walenta, and D. A. Ball. 2003a. Spring germinating jointed goatgrass produces viable spikelets in spring seeded wheat. Weed Science 51:379-385.

Young, F. L., J. P. Yenish, D. L. Walenta, D. A. Ball, and J. R. Alldrege. 2003b. Spring-germinating jointed goatgrass produces viable spikelets in spring seeded wheat. Weed Science 51:379-385.

Young, F., R. Veseth, D. Thill, W. Schillinger, and D. A. Ball. 1995a. Russian Thistle Management under Conservation Systems in the Pacific Northwest Crop-Fallow Regions. Chapter 5. No. 16. In: Pacific Northwest Conservation Tillage Handbook Series. 9 pages.

Young, F., R. Veseth, D. Thill, W. Schillinger, and D. A. Ball. 1995b. Managing Russian thistle under conservation systems in crop-fallow rotations. Pacific Northwest Extension Publication PNW 492. 12 pages.

Zasada, I., L.-M. Dandurand, C. Gleason, C. H. Hagerty, and R. E. Ingham, R. E. 2018. Plant-parasitic nematodes of the Pacific Northwest: Idaho, Oregon and Washington. Pages 221-239. In. S. A. Subbotin and J. J. Chitambar (editors). Plant Parasitic Nematodes in Sustainable Agriculture of North America: Volume 1. Canada, Mexico and Western USA. Springer. 250 pages.

Zuzel, J. F. 1981. Conditional flow simulation: a stochastic forecast model. Water Resources Research 17:595-601.

Zuzel, J. F. 1994. Runoff and soil erosion phenomena in the dryland grain growing region of the Pacific Northwest, USA. Trends in Hydrology 1:209-216.

Zuzel, J. F., R. R. Allmaras, and R. Greenwalt. 1982a. Runoff and soil erosion on frozen soils in northeastern Oregon. Journal of Soil and Water Conservation 37:351-354.

Zuzel, J. F., R. R. Allmaras, and R. N. Greenwalt. 1982b. Report on quality of precipitation, runoff and erosion plot data from the Columbia Plateau Conservation Research Center. Pages 124-129. In: The Quality of Agricultural Research Service Watershed and Plot Data. C. W. Johnson (editor). USDA-ARS. ARM-W-31. 184 pages.

Zuzel, J. F., R. R. Allmaras, and R. N. Greenwalt. 1993. Temporal distribution of runoff and soil erosion at a site in Northeastern Oregon. Journal of Soil and Water Conservation 48:373-378.

Zuzel, J. F., R. N. Greenwalt, and R. R. Allmaras. 1983. Rain on snow: shallow, transient snowpacks with frozen soils. Pages 67-75. In: Proceedings of Western Snow Conference (J. Meiman, editor). Vancouver, WA.

Zuzel, J. F., and R. Karow. 1988. Weather Wizard. Oregon State University Extension Service Software. Special Report No. 831. Corvallis, OR.

Zuzel, J. F., and B. Miller. 1990. Weather wizard for Eastern Washington. A weather data program. MCP 0010 Version 1.0 (Computer software). Cooperative Extension, Washington State University, Pullman, WA

Zuzel, J. F., and J. L. Pikul, Jr. 1987. Infiltration into a seasonally frozen agricultural soil. Journal of Soil and Water Conservation 42:447-450.

Zuzel, J. F., and J. L. Pikul, Jr. 1990. Frozen soil, runoff: and soil erosion research in Northeastern Oregon. Pages 4-10. In: Proceedings of the International Symposium on Frozen Soil Impacts on Agricultural Range and Forest Lands, K. R. Cooley (editor). U.S. Army Corps of Engineer's Cold Regions Research and Engineering Laboratory Special Report 90-1. Hanover, NH.

Zuzel, J. F., and J. L. Pikul, Jr. 1993. Effects of straw mulch on runoff and erosion from small agricultural plots in Northeastern Oregon. Soil Science 156:111-117.

Zuzel, J. F., J.,L. Pikul, Jr., and R. N. Greenwalt. 1986. Point probability distributions of frozen soil. Journal of Climate and Applied Meteorology 25:1681-1686.

Zuzel, J. F., J. L. Pikul, Jr., and P. E. Rasmussen. 1990. Tillage and fertilizer effects on water infiltration. Soil Science Society of America Journal 54:205-208.

Zwer, P. K., M. G. Mosaad, A. A. Elsidaig, and R. W. Rickman. 1994a. Effect of Russian wheat aphid on wheat root and shoot development in resistant and susceptible genotypes. Crop Science 34:650-655.

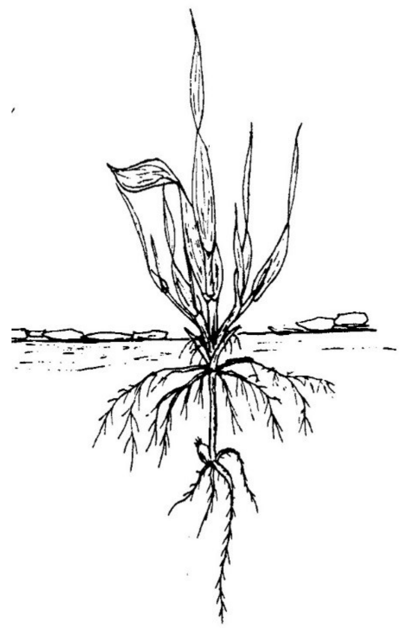
Zwer, P. K., R. F. Park, and R. A. McIntosh. 1992. Wheat stem rust in Australia--1969-1985. Australian Journal of Agricultural Research 43:399-432.

Zwer, P. K. and C. O. Qualset. 1992. Genes for resistance to stripe rust in four spring wheat varieties 1. Seedling responses. Euphytica 58:171-181.

Zwer, P. K., and C. O. Qualset. 1994. Genes for resistance to stripe rust in spring wheat varieties. 2. Adult plant responses. Euphytica 74:109-115.

Zwer, P. K, C. R. Rohde, R. J. Metzger, C. F. Morris, W. E. Kronstad, M. F. Kolding, and R. S. Karow. 1994b. Registration of 'Rohde' wheat. Crop Science 34:1127.

Zwer, P. K., A. Sombrero, R. W. Rickman, and B. Klepper. 1995. Club and common wheat yield component and spike development in the Pacific Northwest. Crop Science 35:1590-1597.



Appendix 4 – List of Dryland Exper. Station Special Reports: 1976-2010

This table shows reports published in the annual 'Special Reports' from scientists based at or working at Pendleton, representing the Columbia Basin Agricultural Research Center and the Columbia Plateau Conservation Research Center. The first and second columns of the table list the year in which the report was published and the OSU-assigned number for that Special Report (SR#). The remaining columns show the pages, topic sorting code, titles and authors. For easier searching, the electronic version of this table can be sorted by columns, such as year, topic, and last name of the first author. For the print edition shown below, the table was sorted by topic code (#1), author name (#2) and year (#3). Some papers involved multiple topics. Those papers were listed under only a single topic; e.g., they were not repeated. Examples are papers that address relationships between effects of nitrogen fertilizer on rate of water extraction by wheat plants, or effects of nitrogen fertilizer on disease severity. Inspect multiple sorting codes to identify those relationships. The research centers did not publish and written summary reports after 2009. Manuscripts are now either published in peer-reviewed technical journals or, in very few instances, in extension publications. A small number of findings are now reported via transitory social media platforms. These publications may be cited by changing the abbreviated listing shown in this table to the following format: Rickman, R.W., and B. Klepper. 1987. Estimating seeding rate increase to compensate for delayed planting. Oregon Agricultural Experiment Station Special Report 797:41-47.

Code	Subject	Code	Subject	Code	Subject
Ag	Agronomy - not categorized	**Lm**	Long-term plots (Moro)	**Sp**	Soil physics
Asb	Stubble burning	**Lo**	Long-term plots (other locations)	**Sq**	Soil quality and sustainability
Bb	Barley breeding and testing	**Lp**	Long-term plots (Pendleton)	**St**	Seed treatment with pesticide
Bo	Breeding & testing of other crops	**Nte**	New technology - field equipment	**Sw**	Soil water
Bw	Wheat breeding & testing	**Nto**	New technology - other	**T**	Tillage
Cb	Brassica crops	**Pf**	Pathology - fungi	**W**	Weeds
Co	Other crops	**Pn**	Pathology - nematode	**Xa**	Authors
Cp	Pea & lentil crops	**Po**	Pathology - other causes	**Xg**	Growing degree days
E	Erosion	**R**	Rainfall	**Xi**	Introduction
Fb	Fertility studies on barley	**Sa**	Soil acidification	**Xpr**	Precipitation (Moro & Pendleton)
Fw	Fertility studies on wheat	**Sc**	Soil chemistry	**Xpu**	Publications
Gd	Plant growth & decomposition	**Sm**	Soil microbiology	**Xr**	Map of research sites
H	Hydrology	**Som**	Soil organic matter	**Xtm**	Temperature (Moro)
I	Insects			**Xtm**	Temperature (Pendleton)

Year	SR #	Page	Topic	Title	Authors
1983	680	43-44	Ag	Effect of nitrogen, phosphorus, and planting date on plant growth and development, water uptake, and water stress in dryland wheat production	Agamennoni, R., & F.E. Bolton
1994	933	40-44	Ag	Effect of methanol applications on crops in eastern Oregon	Albrecht, S.L., C.L. Douglas, Jr., E.L. Klepper, P.E. Rasmussen, R.W. Rickman, R.W. Smiley, D.E. Wilkins, & D.J. Wysocki
2001	1026	16-21	Ag	Profitability of research center direct-seed cropping systems	Bechtel, A.
1992	894	18-23	Ag	Cereal emergence and establishment in conservation tillage systems	Chastain, T.G., & K.J. Ward
1991	879	19-21	Ag	Planting quality of pre-harvest sprouted wheat seed	Chastain, T.G., B.L. Klepper, & D.E. Wilkins
2000	1012	39-45	Ag	Effects of seeding date on yield, water use, and disease of winter wheat and spring wheat cultivars	Chen, C., W.A. Payne, R. Smiley, L. Patterson, & K. Rhinhart
1993	909	55-58	Ag	Tillage, seed size, and seed density effects on early plant development and grain yield of winter wheat	Douglas, C.L. Jr., D.E. Wilkins, R.W. Smiley, & D.B. Churchill
1987	797	48-51	Ag	Agronomic zones in the Pacific Northwest	Douglas, C.L. Jr., J.F. Zuzel, R.W. Rickman, & B.L. Klepper
1978	na	74-75	Ag	Water injection into the seed zone as an aid to emergence of dryland cereals	Estes, J.P., & F.E. Bolton
2007	1074	72-81	Ag	Planting date and seeding rate effects on the yield of winter and spring wheat varieties - Results from the 2005-2006 cropping year	Flowers, M., C.J. Peterson, S. Petrie, S. Machado, & K. Rhinhart
2008	1083	26-35	Ag	Early and delayed planting effects on winter wheat variety performance	Flowers, M., C.J. Peterson, S. Petrie, S. Machado, K. Rhinhart, & J. Chatelain
1981	623	43-44	Ag	Best management practices (BMP) demonstration and evaluation project; five-county north central Oregon area; 1978-1981	George, G.O.
1987	797	65	Ag	Wheat seed treatments with yield enhancing agents	Grabe, D., F. Bolton, & C. Garbacik
1976	459	7	Ag	Cereal seed technology research	Grabe, D.F., F. Mathenge, V. Assuncao, & B. Rotta
1988	827	31-32	Ag	Performance of yield-enhancing agents in winter wheat	Grabe, D.F., F.E. Bolton, & C. Garbacik
1989	840	57-61	Ag	Response of winter wheat to yield-enhancing agents	Grabe, D.F., F.E. Bolton, C. Garbacik, & J. DeNoma
1979	547	34-37	Ag	Crown temperatures of winter wheat	Klepper, B., & R.W. Rickman
2004	1054	117-119	Ag	Seed sizing as a tool for drill settings in precision agriculture	Macnab, S.
1979	547	28-29	Ag	Effects of temperature on heading of winter wheat	Metzger, R.J.

1981	623	60-62	Ag	The effect of water injection and starter fertilizer on stand establishment and components of yield	Noori-Fard, F., & F.E. Bolton
1982	661	16-18	Ag	The effect of water injection on stand establishment components	Noori-Fard, F., & F.E. Bolton
1997	977	43-46	Ag	Major factors influencing wheat yield improvement during the last thirty years	Payne, W.A., P.E. Rasmussen, & R. Goller
2007	1074	36-45	Ag	Agronomic performance of food barley at Pendleton and Moro	Petrie, S., P. Hayes, A. Ross, J. Rey, K. Rhinhart, & A. Corey
2006	1068	93-102	Ag	Yield comparison and economic analysis of conventional and direct-seed research at Pendleton	Petrie, S., S. Albrecht, & D. Long
1995	946	42-45	Ag	Long-term trends in cereal yields at Pendleton	Rasmussen, P.E., & R.W. Smiley
1989	840	11-13	Ag	Improving grain yield: 60-years of progress	Rasmussen, P.E., C.R. Rohde, & R.W. Smiley
1987	797	41-47	Ag	Estimating seeding rate increase to compensate for delayed planting	Rickman, R.W., & B. Klepper
1986	776	50-51	Ag	Yield, development-rate correlations for winter wheat	Rickman, R.W., E.L. Klepper, & C.R. Crampton
1979	547	43-49	Ag	Emergence of winter wheat and winter barley as influenced by field soil temperatures	Russelle, M.P., & F.E. Bolton
1988	827	40-42	Ag	Wheel track damage in cereals	Rydrych, D.J., & D.E. Wilkins
1993	909	50-54	Ag	Yield components and crop characteristics of no-tillage winter wheat grown in a wheat-fallow rotation	Schillinger, W.F., & F.E. Bolton
1999	999	49-58	Ag	Agronomic rates of biosolids for soft white winter wheat production	Shearin, T.E., D.M. Sullivan, S. Macnab, E. Jacobsen, D.J. Wysocki, & R.S. Karow
2005	1061	30-50	Ag	Small grain acreage and management trends for eastern Oregon and Washington	Smiley, R., M. Siemens, T. Gohlke, & J. Poore
2004	1054	30-34	Ag	Competition for water by windbreak trees: Distance of impact on wheat yield	Smiley, R., S. Machado, & K. Rhinhart
1992	894	86-87	Ag	Estimate of cultivated acres for agronomic zones in the Pacific Northwest	Smiley, R.W.
1997	977	16-19	Ag	Biosolids in Columbia Basin dryland cropping systems	Sullivan, D., S. Macnab, E. Jacobsen, D. Wysocki, & R. Karow
1998	989	41-46	Ag	Optimum biosolids application rates for soft white winter wheat	Sullivan, D., S. Macnab, E. Jacobsen, D. Wysocki, & R. Karow
2010	na	18-p. pdf	Ag	Plant community development in a dryland CREP in northeastern Oregon	Williams, J.D., H.M. Hartman, L.M. Spencer, & J.O. Loiland
2006	1068	103-110	Ag	Using seed size, planting date, and expected yield to adjust dryland winter wheat seeding rates	Wysocki, D., & M. Corp

1995	946	105-109	Asb	Is burning an effective management practice for the Pacific Northwest cereal region?	Albrecht, S.L., P.E. Rasmussen, K.W. Skirvin, & R.H. Goller
2000	1012	46-50	Asb	Burn or bale: Effect on biomass and nutrients	Douglas, C.L. Jr., & S.L. Albrecht
1976	459	5	Bb	Malting barley	Boulgar, M.
1978	na	61	Bb	Winter malting barley for eastern Oregon	Boulger, M.C.
1980	571	39-43	Bb	Winter malting barleys for Oregon	Boulger, M.C., & M.F. Kolding
2002	1040	88-92	Bb	From winter barley to cold beer	Hayes, P., A. Corey, T. Filichkin, L. Marques-Cedillo, S. Petrie, K. Rhinhart, & J. VonZitzewitz
1996	961	59-63	Bb	Toward a winter malting barley	Hayes, P., F. Chen, A. Corey, & A. Pan
1991	879	26-30	Bb	Practical applications of barley gene mapping	Hayes, P.M.
1992	894	81-85	Bb	Barley breeding for the Columbia Basin	Hayes, P.M.
1990	860	18-19	Bb	Development of winter barley varieties	Hayes, P.M., A.E. Corey, & R.W. Smiley
1985	738	35-38	Bb	Wallowa County no-till spring barley trials 1984	Karow, R., & D. Dickens
1979	547	38-42	Bb	A winter barley for north central Oregon; FB 73123, Ione/Luther	Kolding, M.F.
1984	713	6-10	Bb	Winter survival of fall planted spring barley in the Columbia Basin	Kolding, M.F.
1980	571	30-38	Bb	Improvement of the winter feed barleys for north central Oregon	Kolding, M.F., & M.K. Boulger
1992	894	76-80	Bb	Gwen, PI 554155, syn FB77796: A new winter barley	Kolding, M.F., J. Berdahl, W. Kronstad, & M. Verhoeven
1976	459	8-10	Bo	Development of high yielding nutritionally superior feed grains	Kolding, M.F.
1978	na	63-64	Bo	Cereal hay for Oregon	Kolding, M.F.
1979	547	53-57	Bo	Triticale development for eastern Oregon	Kolding, M.F., & R.J. Metzger
1978	na	37	Bo	Developing peas for resistance to soil-borne disease	Kraft, J.M.
1995	946	15-18	Bw	Current Status of the statewide breeding program	Barnum, M., R. Dovel, E. Jacobsen, S. James, R. Karow, R. Knight, W. Kronstad, M. Moore, R. Roseburg, M. Verhoeven, & P. Zwer
2001	1026	22-41	Bw	Statewide cereal variety testing program	Bassinette, J.P., R.S. Karow, S.W. McDonald, K. Rhinhart, & R.W. Smiley
2005	1061	51-57	Bw	USDA-ARS club wheat breeding in Oregon	Blake, N, K. Garland Campbell, S. Petrie, & L. Little
2002	1040	61-75	Bw	Statewide cereal variety testing program	Blake, N., J.P. Bassinette, R.S. Karow, K. Rhinhart, & S. Petrie
1986	776	20-25	Bw	Wheat varietal development: Pendleton, 1985	Broich, C.R., N. Scott, A.E. Corey, R. Knight, & W.E. Kronstad
1988	827	12-19	Bw	Wheat varietal development: Pendleton, 1987	Broich, S., M. Verhoeven, C. Love, N. Scott, R. Knight, M. Moore, D. Kelley, & W. Kronstad

1989	840	23-34	Bw	Wheat varietal development: A market perspective	Broich, S.L., M. Verhoeven, N.S. Scott, C.S. Love, D. Kelly, R. Knight, M. Moore, & W.E. Kronstad
1987	797	23-28	Bw	Cereal varietal development: Pendleton 1986	Broich, S.L., P.M. Hayes, M. Verhoeven, C.S. Love, A.E. Corey, N. Scott, M.D. Moore, R. Knight, & W.E. Kronstad
2008	1083	20-25	Bw	USDA-ARS club wheat breeding in Oregon	Chatelain, J., K. Garland Campbell, C. Hoagland, & S. Petrie
2009	1091	34-38	Bw	USDA-ARS club wheat breeding in Oregon	Chatelain, J., K. Garland Campbell, C. Hoagland, & S. Petrie
2010	na	8-p. pdf	Bw	USDA-ARS club wheat breeding in Oregon	Chatelain, J., K. Garland Campbell, C. Hoagland, & S. Petrie
1978	na	62-63	Bw	Hard red winter wheat in the Pacific Northwest	Cholick, F.A.
1980	571	27-29	Bw	Progress in the hard red winter wheat program	Cholick, F.A., & R.N White
1985	738	65-68	Bw	Cereal variety testing	Crampton, C.R.. C.R. Rohde, & K. Van Wagoner
1978	na	26	Bw	Inheritance and association of earliness and grain yield in four winter x spring wheat crosses	Firat, E., W.E. Kronstad, & W.L. McCuistion
2003	1047	32-39	Bw	USDA-ARS club wheat breeding in Oregon	Garland Campbell, K., N. Blake, & L. Little
1988	827	25-26	Bw	Wheat barley varietal development: Pendleton, 1987	Hayes, P., A. Corey, N. Scott, M. Moore, & R. Knight
1997	977	59-72	Bw	State-wide cereal variety testing program trials	Karow, R., E. Marx, H. Ruddenklau, & M. Moore
1996	961	28-36	Bw	State-wide cereal variety testing program trials	Karow, R., H. Ruddenklau, & M. Moore
1995	946	19-41	Bw	Statewide cereal variety testing program trials in the Columbia Basin	Karow, R., P. Zwer, H. Ruddenklau, & M. Moore
1992	894	60-62	Bw	New winter wheat varieties	Karow, R.S., W.E. Kronstad, & M.F. Kolding
1993	909	72-80	Bw	W 301, A new soft white winter wheat	Kolding, M.F.
1996	961	76-79	Bw	Club wheat breeding program progress report	Kronstad, W., M. Moore, K. Morrow, & V. Correa
1980	571	24-27	Bw	Wheat breeding - A never ending battle	Kronstad, W.E., & N.H. Scott
1981	623	22-35	Bw	Progress in the small grain breeding program	Kronstad, W.E., F.A. Cholick, W.L. McCuistion, N.H. Scott, R.N. White, M.C. Boulger, & A.E. Corey
1990	860	28-34	Bw	Hard white wheat for Oregon and current research on disease resistance	Kronstad, W.E., N.H. Scott, C.S. Love, S.E. Rowe, D. Kelly, R. Knight, M. Moore, & M.C. Verhoeven
1979	547	71-75	Bw	Development of new winter varieties of soft white and hard red wheats for eastern Oregon	Kronstad, W.E., W.L. McCuistion, F.A. Cholick, R. Knight, & N.S. Scott
1992	894	63-66	Bw	Breeding for disease resistance in soft white winter wheat	Love, C.S., D.K. Kelly, R.W. Knight, W.E. Kronstad, M.D. Moore, S.E. Rowe, N.H. Scott, & M.C. Verhoeven

1993	909	70-71	Bw	Breeding for disease resistance in winter wheat	Love, C.S., R.J. Metzger, & W.E. Kronstad
1998	989	20-30	Bw	State wide cereal variety testing program	Marx, E., R.S. Karow, & K.J. Morrow
1999	999	22-38	Bw	Statewide cereal variety testing program	Marx, E., R.S. Karow, K.J. Morrow, & R.Smiley
1976	459	11-12	Bw	Winter x spring wheat improvement program	McCuistion, W.L.
2000	1012	51-54	Bw	Club wheat breeding program	McDonald, S.W., K.G. Campbell, & L. Patterson
2000	1012	55-71	Bw	Statewide cereal variety testing program	McDonald, S.W., R.S. Karow, E. Marx, L. Patterson, & R. Smiley
1997	977	47-51	Bw	Oregon's club wheat program - The next step	Moore, M., K. Morrow, V. Correa, & W. Kronstad
2009	1091	63-70	Bw	Dryland adaptation and nitrogen response of waxy spring wheat lines in northeastern Oregon	Petrie, S.
1976	459	22-31	Bw	Recently released varieties of winter and spring wheat and winter and spring barley	Rohde, C.R.
1978	na	12-24	Bw	Cereal variety descriptions	Rohde, C.R.
1979	547	8-21	Bw	Cereal variety descriptions	Rohde, C.R.
1980	571	9-23	Bw	Cereal variety descriptions	Rohde, C.R.
1981	623	1-16	Bw	Cereal variety descriptions	Rohde, C.R.
1982	661	1-3	Bw	Description of new cereal varieties	Rohde, C.R.
1983	680	1-3	Bw	Description of new cereal varieties	Rohde, C.R.
1986	776	8-15	Bw	Description of cereal grain varieties commonly grown in northeastern Oregon	Rohde, C.R.
1987	797	10	Bw	'Oveson'	Rohde, C.R.
1987	797	11-18	Bw	Descriptions of cereal grain varieties commonly grown in northeastern Oregon	Rohde, C.R.
1982	661	3-7	Bw	Cereal breeding and testing project	Rohde, C.R., & D.A. Nason
1986	776	16-19	Bw	Performance of cereal varieties in northcentral Oregon	Rohde, C.R., & K. Van Wagoner
1987	797	19-22	Bw	Performance of cereal varieties in northcentral Oregon	Rohde, C.R., & K. Van Wagoner
1976	459	32	Bw	Wheat breeding program	Rohde, C.R., & W.B. Locke
1977	485	30-42	Bw	Wheat improvement and cereal production tests	Rohde, C.R., & W.B. Locke
1978	na	5-11	Bw	Cereal breeding and testing project	Rohde, C.R., & W.B. Locke
1979	547	1-7	Bw	Cereal breeding and testing project	Rohde, C.R., & W.B. Locke
1980	571	1-8	Bw	Cereal breeding and testing project	Rohde, C.R., & W.B. Locke
1981	623	16-21	Bw	Cereal breeding and testing project	Rohde, C.R., & W.B. Locke
1976	459	32-36	Bw	Planned releases	Rohde, C.R., & W.E. Kronstad
1983	680	3-8	Bw	Cereal breeding and testing project	Rohde, C.R., C.R. Crampton, & K. Van Wagoner
1984	713	1-5	Bw	Cereal breeding and testing project	Rohde, C.R., C.R. Crampton, & K. Van Wagoner

1996	961	14-17	Bw	New varieties on the horizon	Verhoeven, M., M. Moore, & W. Kronstad
1994	933	73-87	Bw	State-wide cereal variety testing program trials in the Columbia Basin	Zwer, P., D. Sutherland, R. Karow, & H. Ruddenklau
1989	840	35-39	Bw	History of club wheat cultivars in the Pacific Northwest	Zwer, P.K.
1994	933	68-72	Bw	Club wheat breeding program: Progress in 1993	Zwer, P.K.
1993	909	81-90	Bw	Club wheat variety improvement	Zwer, P.K., & D.L. Sutherland
1989	840	14-22	Bw	Club wheat improvement and adaptive testing program: Description and performance of winter and spring wheat cultivars	Zwer, P.K., C.R. Rohde, & K.J. Thomas
1991	879	34-46	Bw	Pacific Northwest winter and spring wheat cultivar descriptions	Zwer, P.K., D.L. Sutherland, & K.J. Morrow
1991	879	47-49	Bw	Club wheat breeding program	Zwer, P.K., D.L. Sutherland, & K.J. Morrow
1992	894	67-75	Bw	Club wheat breeding program	Zwer, P.K., D.L. Sutherland, & S.D. Dunnagan
1990	860	10-17	Bw	Pacific Northwest winter and spring wheat cultivar descriptions	Zwer, P.K., K.J. Morrow, & K.H. Van Wagoner
1990	860	20-22	Bw	Club wheat improvement program	Zwer, P.K., K.J. Morrow, & K.H. Van Wagoner
1982	661	23-31	Cb	Oil seed crops	Pumphrey, F.V.
1999	999	68-73	Cb	Direct seeding winter canola into wheat stubble	Wilkins, D., & D. Wysocki
2002	1040	76-80	Cb	Fertilizer placement in annual crop direct-seeded canola	Wilkins, D., D. Wysocki, M. Siemens, S. Ott, B. Correa, & T. Johlke
1993	909	91-94	Cb	Effect of liquid injection on canola emergence	Wilkins, D.E., & D.A. Haasch
2001	1026	77-83	Cb	Effect of fertilizer placement and soil water on emergence of yellow mustard	Wilkins, D.E., D.J. Wysocki, & M.C. Siemens
2009	1091	39-46	Cb	Growing canola on wide row spacing	Wysocki, D., & N. Sirovatka
1994	933	58-60	Cb	Water use by dryland winter canola	Wysocki, D., & S. Ott
1995	946	61-66	Cb	Winter canola stand establishment using a Zimmerman deep furrow drill	Wysocki, D., B. Schillinger, S. Ott, & K. Ward
1997	977	82-85	Cb	Yellow mustard production in semiarid Oregon	Wysocki, D., M. Stoltz, & S. Ott
1991	879	50-55	Cb	Dryland canola production in eastern Oregon	Wysocki, D., M. Stoltz, T. Chastain, & K. Rhinhart
2007	1074	46-51	Cb	Effect of swathing, "pushing," or direct cutting on yield and oil content of dryland winter canola and spring rapeseed in eastern Oregon	Wysocki, D., N. Sirovatka, & P. Thorgersen
2005	1061	58-65	Cb	Growth and nutrient uptake of winter canola at Pendleton, Oregon	Wysocki, D., N. Sirovatka, & S. Ott

1996	961	80-81	Cb	Comparison of harvest techniques on grain yield of winter canola	Wysocki, D., S. Ott, D. Wilkins, & C. Douglas
1992	894	32-37	Cb	Variety and planting date effects on dryland canola	Wysocki, D., S. Ott, M. Stoltz, & T. Chastain
2001	1026	102-110	Co	Narrow-leaf lupin as an alternative crop for Pacific Northwest dryland agriculture	Chen, C., W. Payne, & D. Ball
2004	1054	84-102	Co	Potential alternative crops for eastern Oregon	Machado, S.
2004	1054	35-43	Co	Evaluating chickpea (Garbanzo bean) for adaptability to eastern Oregon	Machado, S., C. Humphreys, B. Tuck, & M. Corp
2003	1047	25-31	Co	Variety, seeding date, and seeding rate effects on grain yield and grain size of chickpeas (*Cicer arientinum* L.) in eastern Oregon	Machado, S., C. Humphreys, B. Tuck, T. Darnell, & M. Corp
2010	na	10-p. pdf	Co	Adaptation and yield of spring and fall sown safflower in northeastern Oregon	Petrie, S., S. Machado, R. Johnson, L. Pritchett, K. Rhinhart, & B. Tuck
1985	738	44-49	Co	Edible legume seed yield and water use	Pumphrey, F.V., T.R. Toll, & B.L. Klepper
2002	1040	37-43	Co	Effects of header modifications on garbanzo bean harvesting losses	Siemens, M.C., M.K. Corp, & R.F. Correa
1994	933	61-63	Co	Spring white lupin production trials	Tuck, B., & E. Jacobsen
2008	1083	86-92	Co	Camelina, a potential oilseed crop for semiarid Oregon	Wysocki, D., & N. Sirovatka
1980	571	43-47	Cp	Dryland variety trials of processing peas in northeast Oregon	Lund, S.
1978	na	34-36	Cp	1977 dryland pea variety trial	Lund, S., & J.M. Kraft
1979	547	49-52	Cp	Dryland variety trials of processing peas in northeast Oregon	Lund, S., & J.M. Kraft
2005	1061	66-72	Cp	Alternate rotation crops: Peas (*Pisum sativum*)	Machado, S., B. Tuck, & C. Humphreys
2006	1068	32-39	Cp	Alternative rotation crops: Lentils (*Lens culinaris*)	Machado, S., B. Tuck, & C. Humphreys
1977	485	1-5	Cp	Green pea yields, rainfall and excess heat	Pumphrey, F.V., & R.E. Ramig
1986	776	31-34	Cp	Pea yield response to high temperature during blooming and pod filling	Pumphrey, F.V., & R.E. Ramig
1990	860	63-65	Cp	Maximum daily temperatures during reproduction and green pea yield	Ramig, R.E., & F.V. Pumphrey
1981	623	56-60	Cp	Tillage, soil moisture, and yield in green pea production	Ramig, R.E., & L.G. Ekin
1987	797	29-30	Cp	Relation between seedling vigor and yield of peas	Wilkins, D.E., & J.M. Kraft
1998	989	47-52	Cp	Seeding peas and barley into heavy cereal residue	Wilkins, D.E., & S. Wuest
1994	933	64-67	Cp	Green pea varietal differences in soil anchoring ability at harvest maturity	Wilkins, D.E., & T. Darnell
1985	738	50-54	Cp	Integrated pest management research for pea production	Wilkins, D.E., L.L. Baarstad, & J.M. Kraft

1979	547	29-33	E	Management for control of soil erosion in northeastern Oregon	Allmaras, R.R., J.L. Pikul, Jr., & C.E. Johnson
1985	738	12-13	E	Rill erosion effect on wheat yield	Douglas, C.L. Jr., & P.E. Rasmussen
1996	961	41-44	E	Nitrogen in surface runoff and sediment	Douglas, C.L. Jr., K.A. King, & J.F. Zuzel
1980	571	114-119	E	Monitoring terrace control of water pollution caused by soil erosion and sediment in Columbia Basin counties, Oregon	George, G.O., S. Lund, & R. Allmaras
1978	na	1-4	E	Measuring soil erosion on the slopes of the Blue Mountains	Johnson, C.E., R.R. Allmaras, G. Fischbacher, & J.L. Pikul, Jr.
1992	894	14-17	E	Residue management for erosion control	Rickman, R., D. Wilkins, C. Douglas, & R. Adelman
1997	977	20-25	E	Contributions to the establishment of TMDL values for the Umatilla River watershed	Rickman, R.W., J.D. Williams, C.F. Clifton, & M. Purser
1996	961	48-51	E	Effect of residue management on predicted soil loss	Wilkins, D., J. Liu, & J. Williams
2008	1083	58-73	E	Soil loss from long-term winter wheat/summer fallow residue and nutrient management experiment at Columbia Basin Agricultural Research Center, Pendleton, Oregon	Williams, J.D.
1997	977	73-76	E	Winter erosion in four residue management systems: Preliminary report	Williams, J.D., D.E. Wilkins, C.L. Douglas, Jr., & R.W. Rickman
2008	1083	74-85	E	Comparison of runoff and soil erosion from no-till and inversion tillage production systems	Wuest, S.W., J.D. Williams, H.T. Gollany, M.C. Siemens, & D.S. Long
1982	661	37-40	E	Soil erosion in a wheat-pea rotation	Zuzel, J.F., R.N. Greenwalt, & R.R. Allmaras
1980	571	109-114	E	Soil erosion in northeastern Oregon: Climatic factors	Zuzel, J.F., R.R. Allmaras, & R. Greenwalt
1993	909	104-108	E	Summary of twelve years of runoff and erosion management at a site in the foothills of the Blue Mountains	Zuzel, J.F., R.R. Allmaras, & R.N. Greenwalt
2002	1040	30-36	Fb	Nitrogen management for winter malting barley	Petrie, S., P. Hayes, J. Kling, K. Rhinhart, & A. Corey
2003	1047	16-24	Fb	Fertilizer management for winter malting barley	Petrie, S., P. Hayes, K. Rhinhart, N. Blake, J. Kling,& A. Corey
1985	738	33-34	Fb	Annual-crop spring barley response to nitrogen, sulfur and phosphorus	Rasmussen, P.E., D.E. Wilkins, & C.L. Douglas, Jr.
2010	na	7-p. pdf	Fb	Specialty spring barley variety and nitrogen rate trials across northeastern Oregon	Wysocki, D., D.L. Walenta, M. Flowers, & N.D. Sirovatka
1977	485	25-26	Fw	Nitrate-nitrogen accumulation and distribution in the soil profile during a fallow grain rotation as influenced by different levels of soil profile moisture	Aktan, S., & F.E. Bolton

2005	1061	87-91	Fw	Winter wheat responses to nitrogen fertilization in a direct-seed winter wheat and chemical fallow	Albrecht, S.L., K.W. Skirvin, & D.S. Long
1984	713	28-29	Fw	Effects of timing and depth of nitrogen application on protein content of hard red winter wheat	Bohle, M.G., & F.E. Bolton
1984	713	26-27	Fw	Sulfur response trial - 1983	Bolton, F.E.
1988	827	33-34	Fw	Liquid starter fertilizers on winter wheat and barley in no-till plantings	Bolton, F.E.
1988	827	35-36	Fw	Source and method of nitrogen fertilizer and herbicide applications in winter wheat, Moro, 1987	Bolton, F.E.
1989	840	52-53	Fw	Liquid starter fertilizers on winter wheat and barley in no-till plantings	Bolton, F.E.
1989	840	54-56	Fw	Nitrogen and herbicide application methods in winter wheat	Bolton, F.E.
1978	na	27-29	Fw	Effect of different levels of fallow moisture on the amount and distribution of nitrate-N in the soil profile	Bolton, F.E., & S. Aktan
1979	547	61-65	Fw	Soil water and nitrate-N accumulation and distribution as influenced by five fallow-crop precipitation patterns	Glenn, D.M., & F.E. Bolton
1981	623	48-51	Fw	Precipitation variation effects on soil nitrogen and nitrogen requirements of winter wheat	Glenn, D.M., & F.E. Bolton
1982	661	12-16	Fw	The effect of nitrogen and phosphorus fertilization on crop development of early and late planted winter wheat	Glenn, M.
2009	1091	27-33	Fw	Hard red winter wheat production in eastern Oregon: Varieties and nitrogen management	Jepsen, D., M. Flowers, C.J. Peterson, S. Petrie, L. Lutcher, D. Wysocki, K. Rhinhart, J. Chatelain, & N. Sirovatka
1985	738	18-21	Fw	Nitrogen fertilization for protein enhancement of hard red spring wheat	Karow, R., J. Brog, J. Leffel, B. Simko, M. Zimmerman, & S. Broich
2009	1091	47-55	Fw	Phosphorus fertilization of late-planted winter wheat into chemical fallow	Lutcher, L., W. Schillinger, D. Wysocki, S. Wuest, & N. Christensen
2005	1061	21-29	Fw	Fertilizer placement effects on direct-seed wheat stands and grain yield	Petrie, S., K. Rhinhart, & N. Blake
2004	1054	20-29	Fw	Chloride fertilization increased winter wheat and barley yield in northeastern Oregon	Petrie, S., P. Hayes, N. Blake, A. Corey, K. Rhinhart, & K. Campbell

1985	738	22-26	Fw	Winter wheat response to rate and placement of nitrogen in two wheat/fallow tillage systems	Ramig, R.E., & L.G. Ekin
1985	738	27-32	Fw	Fertilizer response in 1984: No-till annual cropping of small grains	Ramig, R.E., & L.G. Ekin
1986	776	43-47	Fw	Influence of type and placement of fertilizer on tillering, components of yield, and yield of recropped winter wheat	Ramig, R.E., & L.G. Ekin
1983	680	16-17	Fw	Winter wheat response to nitrogen fertilizer in no-till annual cropping and conventional tillage wheat-fallow rotation	Rasmussen, P.E.
1991	879	13-15	Fw	Residue effects on nitrogen response in wheat	Rasmussen, P.E., & C.L. Douglas, Jr.
1997	977	77-81	Fw	Winter wheat response to nitrogen, sulfur, phosphorus and micronutrients	Rasmussen, P.E., & R.H. Goller
1980	571	48-52	Fw	Effect of starter fertilizer solutions on wheat emergence, stand and fall growth	Rasmussen, P.E., D.E. Wilkins, & R.W. Rickman
1984	713	24-25	Fw	Winter wheat response to nitrogen, sulfur, and phosphorus in three tillage-rotation cropping systems	Rasmussen, P.E., D.E. Wilkins, E.L. Klepper, & R.W. Rickman
1979	547	24-26	Fw	Surface mulches and soil nitrate losses	Rickman, R.W., & B. Klepper
1993	909	48-49	Fw	Long-term influence of tillage method on surface soil nutrient distribution	Schillinger, W.F., & F.E. Bolton
1993	909	95-97	Gd	Above-ground development of five weed species and three cereals common in Oregon cereal production	Ball, D.A., B. Klepper, & D.J. Rydrych
1983	680	37-42	Gd	Winter wheat trials: A case study using degree days	Crampton, C.R., B.L. Klepper, & R.W. Rickman
1985	738	62-64	Gd	Variety leaf development response to growing degree days	Crampton, C.R., R.W. Rickman, & B. Klepper
1977	485	23-24	Gd	Wheat straw decomposition	Douglas, C.L. Jr.
1980	571	68-72	Gd	Temperature and moisture effects on decomposition of wheat straws with different N and S contents	Douglas, C.L. Jr.
1994	933	56-57	Gd	Decomposition of canola residue	Douglas, C.L. Jr., & D.J. Wysocki
1991	879	16-18	Gd	Estimating cereal residue decomposition	Douglas, C.L. Jr., & R.W. Rickman
1999	999	19-21	Gd	Decomposition of wheat and thistle residue	Douglas, C.L. Jr., S.L. Albrecht, T.R. Johlke, K.W. Skirvin, & A.A. Baker
1989	840	40-42	Gd	Stand establishment in club and common wheats	Klepper, B., A. Sombrero, S. Morita, D. Wilkins, R. Rickman, & P. Zwer
1978	na	77-79	Gd	Effects of straw mulch on root development of 'Hyslop' wheat	Klepper, B., & R.W. Rickman
1988	827	51-56	Gd	Emergence of winter wheat in a dry autumn	Klepper, B., D.E. Wilkins, T.R. Toll, & C. Reeder

1993	909	98-100	Gd	Crown and root systems of five weeds and three cereals	Klepper, B., D.J. Rydrych, & D.A. Ball
1986	776	35-36	Gd	Root development in legume plants	Klepper, B., F.V. Pumphrey, & T.R. Toll
1981	623	65-68	Gd	"Twinning" in winter wheat	Klepper, B., R.W. Rickman, & C.M. Peterson
1982	661	8-12	Gd	Tiller and root development on wheat plants	Klepper, B., R.W. Rickman, R.K. Belford, & G.E. Fischbacher
1985	738	39-43	Gd	Shoot and root development in five legumes	Klepper, B., T.R. Toll, & F.V. Pumphrey
1989	840	43-45	Gd	Root system development of common and club wheats	Morita, S., C.L. Douglas, B.L. Klepper, R.W. Rickman, A. Sombrero, & D.E. Wilkins
1976	459	20-21	Gd	Root growth, water use and grain production	Rickman, R.W.
1984	713	17-23	Gd	Tiller, leaf and root appearance in winter wheat: Unstressed and stressed development patterns	Rickman, R.W., & B. Klepper
1983	680	28-36	Gd	Using air temperature to anticipate wheat crop development	Rickman, R.W., & B.L. Klepper
1985	738	55-61	Gd	Development of ground cover by a winter wheat crop	Rickman, R.W., & P.E. Rasmussen
1980	571	78-82	Gd	Tiller production by Stephens wheat	Rickman, R.W., B.L. Klepper, & C.M. Peterson
1989	840	46-51	Gd	Comparison of club and common wheat yield components at two location, Pendleton and Moro	Sombrero, A., P.K. Zwer, B. Klepper, & R. Rickman
1976	459	5	Gd	Some physiological, agronomic, and genetic factors related to wheat stand establishment	Vahabian, M.
1989	840	80-86	Gd	Straw to grain ratios of Stephens winter wheat	Wilkins, D.E., P.E. Rasmussen, & H.P. Collins
1998	989	61-64	H	Watersheds of the Umatilla Basin	Rickman, R.W.
2001	1026	84-95	H	No-till influence on hydrology and stream morphology in dryland crop areas	Williams, J.D., & S.B. Wuest
1998	989	53-60	H	Stream morphological description of the Umatilla River	Williams, J.D., C.F. Clifton, & R.W. Rickman
2000	1012	101-113	H	Introduction and development of a dryland crop riparian conservation project	Williams, J.D., J.O. Loiland, K.M. Camara, & H.B. Williams
2008	1083	36-42	I	Phosphorus fertilizer reduced Hessian fly infestation of spring wheat in northeastern Oregon	Petrie, S., & K. Rhinhart
1982	661	21-22	I	Hessian fly found in eastern Oregon	Rickman, R.W.
1981	623	63-64	I	Hessian fly in northeast Oregon	Rickman, R.W., B. Klepper, P. Rasmussen, D. Wilkins, & K. Pike
2002	1040	44-53	I	Economic impact of Hessian fly on spring wheat	Smiley, R., R. Whittaker, J. Gourlie, K. Rhinhart, E. Jacobsen, S. Easley, & K. Kidwell
1990	860	23-27	I	Breeding for resistance to the Russian wheat aphid club wheat improvement program	Zwer, P.K.

2007	1074	82-91	Lm	Long-term experiments at Columbia Basin Agricultural Research Center at Moro and Center of Sustainability at Heppner, 2005-2006	Machado, S., L. Pritchett, E. Jacobsen, R. Smiley, D. Ball, S. Petrie, D. Wysocki, S. Wuest, H. Gollany, & W. Jepsen
2006	1068	40-49	Lm	Long-term experiments at CBARC-Moro and Center of Sustainability, Heppner, 2005	Machado, S., L. Pritchett, E. Jacobsen, S. Petrie, D. Smiley, D. Ball, D. Wysocki, S. Wuest, H. Gollany, & W. Jepsen
2008	1083	109-124	Lm	Long-term experiments at CBARC-Moro and Center of Sustainability-Heppner, 2006-2007	Machado, S., L. Pritchett, E. Jacobsen, S. Petrie, D. Smiley, D. Ball, D. Wysocki, S. Wuest, H. Gollany, & W. Jepsen
2009	1091	114-129	Lm	Long-term experiments at CBARC-Moro and Center of Sustainability-Heppner, 2007-2008	Machado, S., L. Pritchett, E. Jacobsen, S. Petrie, D. Smiley, D. Ball, D. Wysocki, S. Wuest, H. Gollany, & W. Jepsen
2004	1054	61-76	Lp	Long-term experiments at CBARC-Pendleton, 2002 and 2003	Machado, S., K. Rhinhart, S. Albrecht, & S. Petrie
2006	1068	5067	Lp	Long-term experiments at Columbia Basin Agricultural Research Center-Pendleton, Oregon 2005	Machado, S., K. Rhinhart, S. Petrie, S. Wuest, & T.R. Johlke
2007	1074	52-71	Lp	Long-term experiments at Columbia Basin Agricultural Research Center-Pendleton, Oregon 2006	Machado, S., K. Rhinhart, S. Petrie, S. Wuest, & T.R. Johlke
2005	1061	72-86	Lp	Long-term experiments at CBARC-Pendleton, 2004	Machado, S., K. Rhinhart, S. Petrie, S. Wuest, R.F. Correa, & T.R. Johlke
1994	933	14-20	Lp	Long-term experiments at the Pendleton Agricultural Research Center	Rasmussen, P.E., & R.W. Smiley
1977	485	43-44	Nte	Research notes: strip tillage and starter fertilizers	Bolton, F.E.
1980	571	88-91	Nte	Agronomic studies on the strip-till planting system	Bolton, F.E.
1983	680	45-48	Nte	Strip-tillage planting in no-till chemical fallow	Bolton, F.E.
1984	713	37-40	Nte	Crop residue distribution by combines	Douglas, C.L. Jr., P.E. Rasmussen, L.L. Baarstad, & R.R. Allmaras
2007	1074	30-35	Nte	Predicting wheat nitrogen status with remote sensing	Eitel, J., & D. Long
1979	547	58-60	Nte	A grain drill for operation in surface residues	Johnson, C.F.
2006	1068	18-24	Nte	On-combine sensing of grain protein concentration in soft white winter wheat	Long, D.S., & A. Baker
2001	1026	61-64	Nte	Evaluation of a residue management wheel for hoe-type no-till drills	Siemens, M.C., D.E. Wilkins, & R.F. Correa
1990	860	58-62	Nte	Performance of a deep furrow drill opener for placement of seed and fertilizer	Wilkins, D.E., & D.A. Haasch
1992	894	38-40	Nte	Opener modification for seeding canola	Wilkins, D.E., & D.A. Haasch

1983	680	14-15	Nte	Grain drill modifications for improved operation in surface residues	Wilkins, D.E., D.A. Haasch, & P.E. Rasmussen
1980	571	83-87	Nte	Effect of grain drill opener on winter wheat emergence	Wilkins, D.E., G. Muilenburg, & R.R. Allmaras
1981	623	51-55	Nte	Deep furrow opener for placement of fertilizer	Wilkins, D.E., G. Muilenburg, B.L. Klepper, & P.E. Rasmussen
1984	713	34-36	Nte	Influence of speed on placement of seed and fertilizer with a USDA modified opener	Wilkins, D.E., P.E. Rasmussen, & D.A. Haasch
1985	738	14-17	Nte	New grain drill opener for placement of seed and fertilizer	Wilkins, D.E., P.E. Rasmussen, W. Warn, & D.A. Haasch
1995	946	96-98	Nto	'D3R': A residue management aid	Douglas, C.L. Jr., R.W. Rickman, & S.E. Waldman
2002	1040	16-29	Nto	USDA-ARS meteorological monitoring in northeastern Oregon	Oviatt, H.S., & D.E. Wilkins
1993	909	101-103	Nto	MODWHT3, A new instrument for your management tool kit	Rickman, R.W., S.E. Waldman, & B.L. Klepper
1978	na	25	Nto	An electronic weighing and data processing system for field use	Scott, N.H.
1993	909	23-27	Nto	Technique for protein separation of soft white winter wheat	Wilkins, D.E., C.L. Douglas, Jr., & D.B. Churchill
1999	999	74-80	Nto	Instrumentation of the long-term crop residue plots for hydrologic and soil erosion evaluation	Williams, J.D., C. Chen, C.L. Douglas, Jr., R.W. Rickman, & W. A. Payne
1996	961	37-40	Nto	The Pacific Northwest rainfall simulator: A research tool for the interior Northwest	Williams, J.D., D.E. Wilkins, D.K. McCool, L.L. Baarstad, B.L. Klepper, & R.I. Papendick
1991	879	11-12	Nto	Weather Wizard: Weather data programs for eastern Oregon	Zuzel, J.F.
1982	661	41-46	Pf	Soil compaction and root diseases of peas	Allmaras, R.R., J.M. Kraft, & J.L. Pikul, Jr.
1991	879	22-25	Pf	High temperature sodium hypochlorite treatment effects on *Tilletia controversa* (TCK) teliospores and wheat seed	Chastain, T.G., & K.J. Ward
2006	1068	25-31	Pf	Molecular diagnostics and breeding in wheat root disease research	Easley, S., C. Watson, J. Sheedy, D. Melanson, R. Descalzo, & R. Smiley
1976	459	6	Pf	Oregon stripe rust project: Crop loss investigations	Emge, R.G., & D. Johnson
1984	713	11-16	Pf	Forecasting foot rot of winter wheat	Grybauskas, A.P., & R.L. Powelson
1981	623	35-42	Pf	A quest for cereal varieties resistant to the minor cereal diseases in eastern Oregon	Kolding, M.F.
1986	776	26-30	Pf	A search for winter cereals adapted to the dwarf bunt (*Tilletia controversa* Kuehn) production areas in and bordering Oregon	Kolding, M.F., W.E. Kronstad, & C. Love
1988	827	20-24	Pf	Breeding dwarf bunt (*Tilletia controversa* Kuhn) resistant winter wheats	Kolding, M.F., W.E. Kronstad, & C. Love
2001	1026	42-52	Pf	Molecular detection of soilborne fungal pathogens of cereals	Melanson, D.L., & S.A. Easley

1976	459	13	Pf	A search for resistance to common and dwarf bunt and its inheritance in wheat hybrids	Metzger, R.J., & B.A. Silbaugh
1978	na	58-60	Pf	Resistance to common and dwarf bunt in common wheats	Metzger, R.J., C.R. Rohde, & M.F. Kolding
1978	na	38-40	Pf	Chemical control of wheat diseases	Powelson, R.L.
1979	547	27-28	Pf	Identification of resistance to take-all root rot, Cercosporella foot rot, and Cephalosporium stripe	Powelson, R.L.
1976	459	14	Pf	Epidemiology and control of fungus-induced disease of wheat	Powelson, R.L., & M.L. Powelson
1980	571	64-67	Pf	Banding ammonium and chloride fertilizers for suppression of take-all root rot of wheat	Powelson, R.L., T.L. Jackson, & M.E. Halsey
1992	894	41-51	Pf	Summary of Rhizoctonia root rot research on wheat and barley	Smiley, R.
1993	909	59-64	Pf	Annual spring barley in high- and low-residue tillage systems	Smiley, R., & D. Wilkins
1994	933	31-39	Pf	Wheat and barley diseases in conservation cropping systems	Smiley, R., & L. Patterson
1995	946	67-72	Pf	Damage to winter wheat from dryland root rot	Smiley, R., & L.-M. Patterson
1995	946	73-80	Pf	Pathogens associated with dryland root rot in Oregon and Washington	Smiley, R., & L.-M. Patterson
1989	840	68-79	Pf	Rhizoctonia root rot of wheat and barley	Smiley, R., D. Wilkins, W. Uddin, S. Ott, K. Rhinhart, & S. Case
2009	1091	79-89	Pf	Variability of the screening test for identifying Fusarium crown rot tolerance in wheat	Smiley, R., H. Yan, J. Sheedy, A. Thompson, S. Easley, R. Whittaker, J. Gourlie, K. Rhinhart, & E. Jacobsen
1999	999	59-67	Pf	Disease management for annual crops in low-rainfall regions	Smiley, R., L. Patterson, K. Rhinhart, & E. Jacobsen
2003	1047	40-52	Pf	Genetic tolerance to Fusarium crown rot of wheat	Smiley, R., R. Whittaker, J. Gourlie, S. Easley, K. Rhinhart, E. Jacobsen, J. Peterson, K. Kidwell, & K. Campbell
1988	827	27	Pf	Soilborne pathogens of cereals in eastern Oregon: Development of a research strategy	Smiley, R.W.
1997	977	30-37	Pf	Karnal bunt and its risk to the Pacific Northwest	Smiley, R.W.
1997	977	52-58	Pf	Rhizoctonia diseases and their management in cereals	Smiley, R.W.
1994	933	21-30	Pf	Wheat diseases and yield in long-term agronomic experiments at the Columbia Basin Agricultural Research Center (Pendleton)	Smiley, R.W., H.P. Collins, P.E. Rasmussen, W. Uddin, K.E.L. Rhinhart, & R.H. Goller
2006	1068	68-77	Pn	Soil profile distribution and management strategies of the root-lesion nematodes *Pratylenchus thornei* and *P. neglectus* in the Pacific Northwest	Sheedy, J., R. Smiley, & S. Easley

2000	1012	79-93	Pn	Root-lesion nematodes in eastern Oregon dryland crops	Smiley, R.
2007	1074	15-29	Pn	Cereal cyst nematode: Distribution, yield reduction, and crop management strategies	Smiley, R., J. Sheedy, J. Pinkerton, S. Easley, A. Thompson, & G. Yan
1993	909	39-47	Pn	Wheat production in soil infested with cereal cyst nematode and fungal pathogens	Smiley, R., R. Ingham, & G. Cook
2004	1054	44-60	Pn	Lesion nematodes reduce yield in annual spring wheat	Smiley, R., R. Whittaker, J. Gourlie, S. Easley, K. Rhinhart, E. Jacobsen, A. Burnett, J. Jackson, D. Kellogg, J. Skirvin, & T. Zeckman
2009	1091	90-103	Pn	Associations among cropping systems, root-lesion nematodes, and wheat yield	Smiley, R., S. Machado, L. Pritchett, E. Jacobsen, A. Thompson, J. Sheedy, S. Easley, & J. Gourlie
2001	1026	65-76	Pn	Survey of nematodes in eastern Oregon and Washington field crops	Smiley, R.W.
1988	827	28-31	Pn	Cereal cyst nematode (*Heterodera avenae*) research and survey in eastern Oregon	Smiley, R.W., J. Pinkerton, R. Ingham, G. Newcomb, G. Cook, & P. Zwer
2008	1083	43-57	Pn	Reducing yield loss from root-lesion nematodes by improving wheat genetics	Smiley, R.W., J.G. Sheedy, A.L. Thompson, S.A. Easley, K.E.L. Rhinhart, G. Yan, & W.R. Jepsen
2009	1091	15-26	Pn	Molecular identification of cyst nematodes from wheat and barley fields	Yan, G., R.W. Smiley, J. Gourlie, A.L. Thompson, & H. Yan
2010	na	11-p. pdf	Pn	Genetic characterization of resistance in wheat to the root-lesion nematode *Pratylenchus thornei*	Yan, G., R.W. Smiley, J. Gourlie, & A.L. Thompson
2008	1083	93-108	Pn	Molecular diagnostics of root-lesion nematodes and cereal cyst nematodes	Yan, G., R.W. Smiley, P.A. Okubara, S.A. Easley, J.G. Sheedy, & A.L. Thompson
2001	1026	53-55	Po	Treatments for control of barley yellow dwarf virus in wheat	Corp, M.K., & P.B. Hamm
1993	909	28-38	Po	Physiologic leaf spot of wheat	Smiley, R.
2006	1068	78-85	R	When can you seed fallow ground in the fall? A historical perspective on fall rain	Petrie, S., & K. Rhinhart
1988	827	62-67	R	Rainfall at the Pendleton and Moro Experiment Stations	Ramig, R.E.
1989	840	92-100	R	Variability of crop-year precipitation	Ramig, R.E.
1977	485	6-10	R	Winter wheat responses to rainfall in a wheat pea cropping sequence	Ramig, R.E., & F.V. Pumphrey
1998	989	35-40	R	Thirty-year rainfall trends and implications for crop yield in the Columbia Plateau	Rasmussen, P.E., W.A. Payne, & R.H. Goller
2005	1061	15-20	R	Possible precipitation outcomes after an abnormally dry winter	Rhinhart, K., & S. Petrie
2009	1091	56-62	R	Probability of rain in September and October at Moro, Oregon	Rhinhart, K., E. Jacobsen, & S. Petrie

1980	571	73-77	Sa	Liming effects in a wheat-pea rotation - A progress report	Allmaras, R.R., K. Ward, & J. Kraft
1978	na	55-58	Sa	Soil acidification from long-term use of ammonium-type nitrogen fertilizers	Allmaras, R.R., K. Ward, P.E. Rasmussen, & C.R. Rohde
1987	797	31-33	Sa	Winter wheat response to lime in a wheat-pea rotation	Rasmussen, P.E., & D.E. Wilkins
1988	827	43-45	Sa	Green pea response to lime in a wheat-pea rotation	Rasmussen, P.E., & D.E. Wilkins
1998	989	15-19	Sc	Carbon dioxide emission from soils following direct seeding	Albrecht, S.L., & D.E. Wilkins
1996	961	97-101	Sc	Carbon dioxide release from the soil during residue decomposition	Albrecht, S.L., C.L. Douglas, Jr., & K.W. Skirvin
1999	999	15-18	Sc	Carbon sequestration by agricultural soils	Albrecht, S.L., C.L. Douglas, Jr., & R.W. Rickman
1996	961	68-70	Sc	Formation of weakly cemented siliceous pans induced by long-term agricultural management	Baham, J., & S. Al-Ismaily
1979	547	22-23	Sc	Silica movement in Walla Walla soils	Douglas, C.L. Jr., & R.R. Allmaras
1980	571	52-56	Sc	Soil nitrate nitrogen mineralization during the fallow in the surface 30 cm (12 inches) under different precipitation levels	Huseyin Senel, A., & F.E. Bolton
2000	1012	24-28	Sm	Soil microbial activity in annual spring wheat and wheat-fallow rotations in the very low rainfall areas of the Columbia Plateau	Albrecht, S.L., W.F. Schillinger, & C.L. Douglas, Jr.
2002	1040	54-60	Sm	Isolation and identification of bacteria in eastern Oregon agricultural soils	Boyle, S.A., & S.L. Albrecht
2002	1040	81-87	Sm	Enumerating soil bacterial populations in the CBARC long-term plots	Boyle, S.A., & S.L. Albrecht
2001	1026	111-117	Sm	Fluorscent diacetate hydrolysis as a method of determining soil microbial activity in Columbia Basin silty loam soils	Smith, D., & S. Albrecht
2000	1012	14-18	Som	Effects of tillage on soil carbon in semiarid cropland	Albrecht, S.L., D.F. Bezdicek, M. Fauci, K.W. Skirvin, & R.W. Rickman
1997	977	38-42	Som	Light fraction soil organic matter in long-term agroecosystems	Albrecht, S.L., H.L.M. Baune, P.E. Rasmussen, & C.L. Douglas, Jr.
2000	1012	19-23	Som	Organic matter fractions from Pacific Northwest soils: Depth and tillage effects	Albrecht, S.L., M. Fauci, K.W. Skirvin, & D.F. Bezdicek
2003	1047	53-57	Som	Soil carbon trends in Pacific Northwest wheat-fallow systems	Albrecht, S.L., S. Machado, & D. Wilkins
1978	na	52-54	Som	Long-term effects of crop residue management on organic matter levels in soil (1931-1976)	Rasmussen, P.E., C.R. Rohde, & N.C. Roager
2001	1026	96-101	Som	Understanding soil organic matter	Wysocki, D.
1983	680	20-22	Sp	Soil frost penetration under conventional and conservation tillage	Greenwalt, R.N., J.L. Pikul, Jr., & J.F. Zuzel
1982	661	31-36	Sp	Formation of soil frost as influenced by crop residue management	Pikul, J.L. Jr.

1989	840	89-91	Sp	Fall tillage to improve water infiltration in frozen soil	Pikul, J.L. Jr., J.F. Zuzel, & D.E. Wilkins
1988	827	46-50	Sp	Tillage impacts on water infiltration	Pikul, J.L. Jr., J.F. Zuzel, & R.N. Greenwalt
1995	946	99-100	Sp	Work in progress: Soil roughness and porosity measurements with acoustics	Rickman, R.W.
1996	961	64-67	Sp	Sound patterns reveal soil roughness and porosity	Rickman, R.W.
1994	933	52-55	Sp	Frozen soil tillage for soil erosion control	Wilkins, D.E., & J.F. Zuzel
1991	879	31-33	Sp	Tilling frozen soil to control water erosion	Wilkins, D.E., J.L. Pikul, Jr., J.F. Zuzel, & D.A. Haasch
2003	1047	69-72	Sp	Seed-soil contact and the role of vapor in germination	Wuest, S.
2006	1068	86-92	Sp	Effects of tillage on water infiltration - Project summary	Wuest, S., J. Williams, & T. Johlke
2009	1091	104-113	Sp	Do high velocity water flow paths develop over time under no-till	Wuest, S.B., T. Johlke, & W. Matlock
1985	738	1-5	Sp	Frequency of frozen soil in northcentral Oregon	Zuzel, J.F., J.L. Pikul, Jr., & R.N. Greenwalt
1995	946	101-104	Sq	Soil quality and soil organic matter	Albrecht, S.L., & P.E. Rasmussen
1996	961	82-84	Sq	Effect of annual burn-notill wheat on soil organic matter content and bulk density	Rasmussen, P.E., & S.L. Albrecht
1993	909	13-22	Sq	Biological and economic sustainability of wheat/fallow agriculture	Rasmussen, P.E., R.W. Smiley, & B. Duff
2000	1012	72-78	Sq	How much carbon can you store in the soil as organic matter?	Rickman, R.W., C.L. Douglas, Jr., & S.L. Albrecht
1999	999	45-48	Sq	Predicting carbon sequestration in agricultural cropland and grassland soils	Rickman, R.W., C.L. Douglas, Jr., S.L. Albrecht, & J.L. Berc
2000	1012	94-100	Sq	Bridging the gap between education and research through soil quality testing	Wilkins, D., & E. Heidemen
1995	946	81-95	St	Seed treatments and genetic resistance for controlling smut diseases in winter wheat	Smiley, R., & L.-M. Patterson
1992	894	52-59	St	Dividend': A potential seed treatment fungicide	Smiley, R., & W. Uddin
2004	1054	120-127	St	Seed treatments for chickpea (Garbanzo bean)	Smiley, R., J. Gourlie, R. Whittaker, S. Easley, K. Rhinhart, E. Jacobsen, A. Burnett, J. Jackson, D. Kellogg, & T. Zeckman
1990	860	35-42	St	Response of wheat yields to fungicides applied as seed treatments or in-row bands	Smiley, R., W. Uddin, S. Ott, D. Wilkins, K. Rhinhart, & S. Case
1990	860	43-48	St	Response of barley yields to fungicide seed treatments	Smiley, R., W. Uddin, S. Ott, D. Wilkins, K. Rhinhart, & S. Case
1996	961	52-58	St	Fungicide seed treatments influence emergence of winter wheat in cold soil	Smiley, R.W., L.-M. Patterson, & C.W. Shelton

1996	961	85-96	St	Fungicide seed treatment effects on emergence of deeply planted winter wheat	Smiley, R.W., L.-M. Patterson, & K.E.L. Rhinhart
1976	459	3-4	Sw	More infiltration, less runnoff and evaporation	Allmaras, R.R., C.L. Douglas & K. Ward
1977	485	19-22	Sw	Chiseling influences on water infiltration and percolation	Allmaras, R.R., K. Ward, & L. Ekin
1978	na	73-74	Sw	Temperature and moisture effects on stand establishment of seven winter wheat cultivars and selected progeny	Conway, M., & W.E. Kronstad
1980	571	56-63	Sw	Precipitation variation, the effect of seasonal precipitation on grain yield, and the nitrogen requirements for dryland winter wheat	Glenn, D.M., & F.E. Bolton
1980	571	92-98	Sw	Soil moisture storage and depletion by winter wheat under five fallow-crop precipitation patterns in a 10-14 inch precipitation area	Henderson, R.L., & F.E. Bolton
1995	946	59-60	Sw	Drought tolerance study on winter wheat	J. Cerono, & W. Kronstad
2003	1047	58-63	Sw	Chemical fallow water storage in a low precipitation zone of north-central Oregon	Lutcher, L.K.
1998	989	31-34	Sw	Hydraulic conductivity functions derived from soil water content data of a long-term experiment	Payne, W.A.
1985	738	6-11	Sw	Water infiltration in frozen soil	Pikul, J.L. Jr., J.F. Zuzel, & R.N. Greenwalt
1983	680	8-13	Sw	Water movement through tillage pans after 52 years of crop residue management	Pikul, J.L. Jr., R.R. Allmaras, & C.R. Rohde
1976	459	15-16	Sw	Conservation tillage effects on water storage and crop yield in Walla Walla and Ritzville soils	Ramig, R.E., & L.G. Ekin
1978	na	65-68	Sw	Soil water storage as influenced by tillage and crop residue management	Ramig, R.E., & L.G. Ekin
1984	713	30-33	Sw	Effect of stubble management in a wheat-fallow rotation on water conservation and storage in eastern Oregon	Ramig, R.E., & L.G. Ekin
1991	879	56-60	Sw	When do we store water with fallow?	Ramig, R.E., & L.G. Ekin
1976	459	17-19	Sw	Nitrogen and sulfur fertilization effects on water relations and growth of non-irrigated white wheat	Rasmussen, P.E.
1977	485	11-18	Sw	Water use by wheat	Rickman, R.W.
1978	na	30-34	Sw	Control of soil water use by wheat root and shoot size	Rickman, R.W.
1978	na	68-72	Sw	Loss of seed-zone moisture prior to planting	Russelle, M.P., & F.E. Bolton

1992	894	24-27	Sw	Late season compaction effects on seed zone water retention in summer fallow	Schillinger, W.F., & F.E. Bolton
1992	894	28-31	Sw	Summer fallow water storage of no-till versus conventional tillage in the Pacific Northwest	Schillinger, W.F., & F.E. Bolton
1995	946	53-58	Sw	Determining seed-zone soil water content	Wilkins, D., D. Wysocki, & R. Adelman
2003	1047	64-68	Sw	Chemical fallow seed-zone soil water content in a dry fall	Wilkins, D.E., S.L. Albrecht, & T.R. Johlke
1979	547	68-71	T	Strip-till planting system	Bolton, F.E.
1999	999	39-44	T	Tillage and rainfall effects upon productivity of a winter wheat-dry pea rotation	Payne, W.A., P.E. Rasmussen, C. Chen, & R. Goller
2009	1091	71-78	T	Using the undercutter sweep in a reduced tillage summer fallow system	Petrie, S.
1983	680	23-28	T	No-till annual cropping	Ramig, R.E., & L. Ekin
1987	797	34-40	T	Fallow systems for semiarid eastern Oregon and Washington	Ramig, R.E., & L.G. Ekin
1988	827	57-61	T	Should I double fallow?	Ramig, R.E., & L.G. Ekin
1979	547	66-68	T	Chemical fallow - A management option	Rydrych, D.J.
1986	776	40-42	T	Effect of paraplowing on winter wheat growth	Wilkins, D.E., P.E. Rasmussen, & J.M. Kraft
2004	1054	103-116	T	Rotary subsoiling to reduce erosion and improve infiltration in newly planted winter wheat after summer fallow	Williams, J.D., S.B. Wuest, W.F. Schillinger, & H.T. Gollany
1999	999	81-84	T	Crop residue and plant health: Research overview and implications for no-till	Wuest, S., & K. Skirvin
2010	na	7-p. pdf	T	One tillage pass can produce highly effective tilled summer fallow	Wuest, S.B., W.F. Schillinger, & M.K. Corp
1993	909	65-69	T	Soil properties, water conservation and yields of winter wheat after subsoil soil tillage	Wysocki, D., P. Nesse, & S. Ott
1994	933	45-47	W	Sulfonylurea herbicide resistance in the Columbia Basin of northeastern Oregon	Ball, D.A., & D.L. Walenta
1995	946	49-52	W	Glyphosate timing effects on downy brome seed production in fallow	Ball, D.A., & D.L. Walenta
1996	961	71-75	W	Early effects of crop rotation on downy brome in dryland winter wheat	Ball, D.A., & D.L. Walenta
2001	1026	56-60	W	Integrated management of jointed goatgrass in winter wheat	Ball, D.A., & F.L. Young
2008	1083	15-19	W	Light-activated sensor sprayer for reduced herbicide use in no-till fallow	Ball, D.A., & L. Bennett
1994	933	48-51	W	Nitrogen fertilizer timing influence on downy brome and winter wheat	Ball, D.A., D.J. Wysocki, & D.L. Walenta

1996	961	45-47	W	Impact of nitrogen fertilization and stubble burning on the downy brome seedbank in a wheat-fallow rotation	Ball, D.A., D.L. Walenta, & P.E. Rasmussen
2004	1054	15-19	W	Agronomic considerations for chemical fallow in dryland wheat production	Ball, D.A., L. Bennett, & L. Lutcher
2004	1054	77-83	W	Post-harvest tillage is inconsistent for managing jointed goatgrass in winter wheat	Ball, D.A., L.H. Bennett, S.M. Frost, & E. Jacobsen
2000	1012	29-38	W	Conservation crop rotations for dryland wheat in downy brome infested areas	Ball, D.A., R.W. Smiley, D.J. Wysocki, & M.A. Stoltz
2010	na	6-p. pdf	W	Wine grape (var. Merlot) response to residual imazethapyr (Pursuit®) in soil	Ball, D.A., S.M. Frost, & L.H. Bennett
2005	1061	92-103	W	Biology of rattail fescue and its management in direct-seeded winter wheat and chemical fallow	Ball, D.A., S.M. Frost, C. Tarasoff, & C. Mallory-Smith
1989	840	62-63	W	Atrazine use in winter cereals under three tillage systems	Bolton, F.E.
1995	946	46-48	W	Effect of crop residue on downy brome emergence	Holowecky, R., B. Klepper, & D. Wilkins
1987	797	52-58	W	Fall seeded barley, wheat, and triticale variety response to fall applied Glean and Finess	Kolding, M.F., & D. Wilson
1976	459	37-40	W	Weed control research	Rydrych, D.J.
1977	485	27-29	W	Cereal rye control in winter wheat	Rydrych, D.J.
1978	na	40-44	W	Selective control of downy brome (cheatgrass) in winter wheat and wintery barley	Rydrych, D.J.
1978	na	45-51	W	Catalogue of herbicides for 1978	Rydrych, D.J.
1980	571	99-101	W	Summary of 1979 weed control research	Rydrych, D.J.
1980	571	102-109	W	Catalog of herbicides for 1980	Rydrych, D.J.
1981	623	45-47	W	Residual Russian thistle control in fall stubble	Rydrych, D.J.
1982	661	18-20	W	"Inversion", a new technique for downy brome control	Rydrych, D.J.
1983	680	18-19	W	Jointed goatgrass - A new weed invader	Rydrych, D.J.
1986	776	37-39	W	A breakthrough for selective cheatgrass control in winter wheat	Rydrych, D.J.
1986	776	48-49	W	Jointed goatgrass cultural control in cereal grains in eastern Oregon	Rydrych, D.J.
1987	797	59-62	W	What's new in selective grass control in cereals	Rydrych, D.J.
1988	827	37-39	W	Cereal cultivar tolerance to Tycor and Picloram	Rydrych, D.J.
1989	840	64-67	W	A history of "Inversion" - A successful technique for weedy brome control in cereals	Rydrych, D.J.

1989	840	87-88	W	Kochia - A potential problem in cereals	Rydrych, D.J.
1990	860	49-51	W	A summary of jointed goatgrass cultural and chemical control in wheat - 1990	Rydrych, D.J.
1990	860	52-55	W	1990 Summary of cheatgrass control in winter cereals	Rydrych, D.J.
1990	860	56-57	W	Green foxtail herbicide resistance in mint	Rydrych, D.J.
1987	797	63-64	W	Herbicide management in CRP perennial grass seed establishment	Rydrych, D.J., & L.C. Burrill
1997	977	26-29	W	Effect of tillage on downy brome seed distribution	Wilkins, D., & B. Whitten
1976-2009			Xi	Introductions and Overviews of the Centers	Authors varied; including S. Lund, R. Smiley, B. Klepper, D. Wilkins, S. Petrie, S. Albrecht, & D. Long
1978-2010			Xpr	Precipitation at Moro and Pendleton (monthly)	Greenwalt, R.
2003-2010			Xtm	Temperature at Moro and Pendleton (monthly)	Greenwalt, R.
1986-2002			Xg	Growing degree days	Greenwalt, R.

Appendix 5 – List of Sherman Station Annual Reports: 1909-1972

Most of these reports include climatic data for the year and long-term averages, the size of field plots and numbers of replications and treatments, and a statement that experiments not otherwise noted were conducted on ground fallowed the previous year. A major change was made in the way climate data was reported. Prior to 1960 the data was presented on a calendar year basis. During 1960, reporting was converted to a winter wheat crop year basis, so that all data for the main crop of the region could be reported in the same table. Reporting lapsed for a few years and, in 1976, was re-established in an abbreviated format; see Appendix 4 'Special Reports.'

Year	Name of Report	Pages	Author(s)
1909	Eastern Oregon Dry-Farming Exp. Sta.	30	H.D. Scudder & W.M. Jardine
1910	Moro Exp. Station	57	H.D. Scudder & O. Beaty
1911	Eastern Oregon Dry-Farming Substation	91	H.J.C. Umberger
1912	Eastern Oregon Dry-Farming Substation	106	D.E. Stephens
1913	Eastern Oregon Dry-Farming Substation	134	D.E. Stephens
1914	Eastern Oregon Dry-Farming Substation	133	D.E. Stephens
1915	Eastern Oregon Dry-Farming Substation	189	D.E. Stephens & C.E. Hill
1916	Eastern Oregon Dry-Farming Substation	133	D.E. Stephens
1916	Cereal Nursery & Breeding Work at EODFS	133	F.J. Schneiderhan
1917	Eastern Oregon Dry-Farming Substation	?	D.E. Stephens & C.E. Hill
1917	Forage Crop Investigations	?	C.E. Hill
1917	Cereal Nursery & Breeding Work at EODFS	?	D.E. Stephens & F.J. Schneiderhan
1918	Sherman County Branch Station	82	D.E. Stephens
1918	Forage Crop Investigations	?	C.E. Hill
1918	Cereal Nursery & Breeding Investigations at EODFS	?	D.E. Stephens
1919	Sherman County Branch Station	115	D.E. Stephens
1919	Soil Moisture Investigation at Sherman Station	77	D.E. Stephens
1919	Winter & Spring wheat Nurseries in CA, OR & WA	?	J.A. Clark
1920	Sherman County Branch Station	135	D.E. Stephens
1920	Soil Moisture & Nitrate Investigation at SCBES	?	D.E. Stephens
1921	Sherman County Branch Station	215	D.E. Stephens
1921	Soil Moisture & Nitrate Investigation at SCBES	?	G.A. Mitchell & D.E. Stephens
1922	Sherman County Branch Station (+ soil & moisture)	169	G.A. Mitchell & D.E. Stephens
1923	Sherman County Branch Station	169	D.E. Stephens, B.B. Bayles & G.A. Mitchell
1923	Soil Moisture & Fertility Investigation at SCBES	?	G.A. Mitchell & D.E. Stephens
1924	Sherman County Branch Station	320	D.E. Stephens & G.A. Mitchell
1924	Cereal Nursery & Breeding Investigations at EODFS	?	B.B. Bayles
1925	Sherman County Branch Station	233	D.E. Stephens & G.A. Mitchell
1925	Cereal Nursery & Breeding Investigations at EODFS	?	B.B. Bayles
1926	Sherman County Branch Station	214	D.E. Stephens & G.A. Mitchell
1926	Cereal Nursery & Breeding Investigations at EODFS	?	B.B. Bayles
1927	Sherman County Branch Station	207	D.E. Stephens & G.A. Mitchell
1928	Sherman County Branch Station	173	D.E. Stephens & G.A. Mitchell
1927	Cereal Nursery & Breeding Work	244	J.F. Martin & G.A. Mitchell
1928	Cereal Nursery & Breeding Work	259	J.F. Martin & G.A. Mitchell
1929	Sherman County Branch Experiment Station	181	D.E. Stephens & M.M. Oveson
1929	Cereal Nursery & Breeding Investigations at SCBS	132	J.F. Martin
1929	Pendleton Field Station	181	D.E. Stephens & G.A. Mitchell
1930	Sherman County Branch Experiment Station	170	D.E. Stephens & M.M. Oveson
1930	Cereal Nursery & Breeding Investigations at SCBES	149	J.F. Martin
1931	Sherman County Branch Station	200	D.E. Stephens & M.M. Oveson
1931	Cereal Nursery & Breeding Investigations at SCBES	?	R.B. Webb
1932	Sherman Branch Experiment Station	174	D.E. Stephens & M.M. Oveson
1932	Cereal Nursery & Breeding Investigations at SCBES	?	R.B. Webb
1933	Sherman Branch Station	181	D.E. Stephens & M.M. Oveson

1933	Cereal Nursery & Breeding Investigations	?	R.B. Webb
1934	Sherman Branch Experiment Station	184	D.E. Stephens & M.M. Oveson
1934	Cereal Nursery and Breeding Investigations	?	R.B. Webb
1935	Sherman Branch Station	201	D.E. Stephens & M.M. Oveson
1935	Cereal Nursery and Breeding Investigations	?	R.B. Webb
1936	Sherman Branch Experiment Station	?	D.E. Stephens, M.M. Oveson & R.B. Webb
1937	Sherman County Branch Experiment Station	217	D.E. Stephens & M.M. Oveson
1938	Sherman County Branch Experiment Station	216	M.M. Oveson & D.E. Stephens
1939	Sherman County Branch Experiment Station	238	M.M. Oveson & R.B. Hoskinson
1940	Sherman County Branch Experiment Station	268	M.M. Oveson, R.W. Henderson & R.B. Hoskinson
1941	Sherman County Branch Experiment Station	291	M.M. Oveson, Leon Hubbard & R.B. Hoskinson
1942	Sherman County Branch Experiment Station	309	M.M. Oveson, Leon Hubbard & R.B. Hoskinson
1943	Sherman County Branch Experiment Station	264	M.M. Oveson, O.S. Weaver & R.B. Hoskinson
1943	Cereal Nursery and Breeding Investigations	?	O.S. Weaver & M.M. Oveson
1944	Sherman County Branch Experiment Station	249	M.M. Oveson, O.S. Weaver & R.B. Hoskinson
1944	Cereal Nursery and Breeding Investigations	?	M.M. Oveson & O.S. Weaver
1945	Sherman County Branch Experiment Station	234	M.M. Oveson & R.B. Hoskinson
1946	only 88 tables of data; no descriptive verbiage	120	M.M. Oveson
1946	Cereal Nursery and Breeding Investigations	?	M.M. Oveson & J.T. McDermid
1947	only 85 tables of data; no descriptive verbiage	150	M.M. Oveson
1947	Cereal Nursery and Breeding Investigations	?	M.M. Oveson & W.E. Hall
1948	No station reports for 1948, 1949 and 1950	-	-
1948	Cereal Nursery and Breeding Investigations	204	W.E. Hall
1949	Cereal Nursery and Breeding Investigations	?	W.E. Hall
1951	Sherman Experiment Station	260	G.A. Mitchell, W. Hall & R.B. Hoskinson
1952	Sherman Experiment Station	285	G.A. Mitchell, W. Hall & R.B. Hoskinson
1953	No written report; 149 tables of datas	-	-
1954	Sherman Branch Experiment Station	247	W. Hall & R.B. Hoskinson
1955	Sherman Branch Experiment Station	191	W. Hall & R.B. Hoskinson
1956	Sherman Branch Experiment Station	173	W. Hall & H. Hailey
1957	Sherman Branch Experiment Station	207	W. Hall, W.F. Wright & H. Hailey
1958	Sherman Branch Experiment Station	218	W. Hall, W.F. Wright, H. Hailey & L. Mersinger
1959	Sherman Branch Experiment Station	≈250	W. Hall, H. Hailey & L. Mersinger
1960	Sherman Branch Experiment Station	≈250	W. Hall & L. Mersinger
1961	Sherman Branch Experiment Station	≈250	W. Hall, L. Mersinger & R. Bernards
1962	Sherman Branch Experiment Station	≈250	W. Hall, D. Graham, L. Mersinger & R. Bernards
1963	Sherman Branch Experiment Station	≈250	W. Hall, D. Graham & L.C. Mersinger
1964	Sherman Branch Experiment Station	≈200	J.T. McDermid & L.C. Mersinger
1965	Sherman Branch Experiment Station	96	J.T. McDermid & L.C. Mersinger
1966	Sherman Branch Experiment Station	175	J.T. McDermid & L.C. Mersinger
1967	Sherman Branch Experiment Station	197	J.T. McDermid & L.C. Mersinger
1968	Sherman Branch Experiment Station	183	J.T. McDermid & L.C. Mersinger
1969	Sherman Branch Experiment Station	169	J.T. McDermid & L.C. Mersinger
1970	Sherman Branch Experiment Station	188	J.T. McDermid & L.C. Mersinger
1971	Sherman Branch Experiment Station	188	J.T. McDermid & L.C. Mersinger
1972	Sherman Branch Experiment Station	174	J.T. McDermid & L.C. Mersinger
1973	No report	-	-

Appendix 6 – List of Pendleton Station Annual Reports: 1929-1976

Most of these reports include climatic data for the year and long-term averages, the size of field plats, and numbers of replications and treatments. Some of the 'missing' reports may not have been written. In 1976, reporting was changed to an abbreviated and voluntary format; see Appendix 4 'Special Reports.'

Year	Annual Report Topic	Pages	Author(s)
1929-1930	**Pendleton Field Station**	15	D.E. Stephens and G.A. Mitchell
1931	Pendleton Experiment Station	155	G.A. Mitchell & M.M. Oveson
1932	Pendleton Experiment Station	177	G.A. Mitchell & M.M. Oveson
1933	Pendleton Experiment Station	166	G.A. Mitchell & M.M. Oveson
1934	Pendleton Experiment Station	179	G.A. Mitchell & M.M. Oveson
1935	Pendleton Experiment Station	194	G.A. Mitchell & M.M. Oveson
1936	Pendleton Experiment Station	209	G.A. Mitchell & M.M. Oveson
1937	Pendleton Experiment Station	215	G.A. Mitchell & M.M. Oveson
1938	Pendleton Experiment Station		(missing)
1939	Pendleton Experiment Station		(missing)
1940	Pendleton Experiment Station		(missing)
1941	Pendleton Experiment Station	160	G.A. Mitchell
1942	Pendleton Experiment Station	81	G.A. Mitchell
1943	Pendleton Experiment Station		(missing)
1944	Pendleton Experiment Station	66	G.A. Mitchell
1945	Pendleton Experiment Station		(missing)
1946	Pendleton Experiment Station		(missing)
1947	Pendleton Experiment Station		(missing)
1948	Pendleton Experiment Station	86	G.A. Mitchell
1949	Pendleton Experiment Station	150	M.M. Oveson & C.H. Ramage
1950	Pendleton Experiment Station	182	M.M. Oveson & C.H. Ramage
1951	Pendleton Experiment Station	203	M.M. Oveson, C.H. Ramage & H.M. Waddoups
1952	Pendleton Experiment Station	216	M.M. Oveson, H.M. Waddoups, C.H. Ramage & T.R. Horning
1953	Pendleton Experiment Station	225	M.M. Oveson, H.M. Waddups & T.R. Horning
1954	Pendleton Experiment Station: I	220	M.M. Oveson, T.R. Horning, H.M. Waddoups & C.J. Gerard
1954	Pendleton Experiment Station: II	226	M.M. Oveson, T.R. Horning, H.M. Waddoups & C.J. Gerard
1955	Pendleton Experiment Station: I	185	M.M. Oveson, T.R. Horning, K.G. Woodward & C.J. Gerard
1955	Pendleton Experiment Station: II	210	H.M. Waddoups
1956	Pendleton Experiment Station: I	204	M.M. Oveson, T.R. Horning, H.M. Waddoups & C.J. Gerard
1956	Pendleton Experiment Station: II	67	K.G. Woodward
1957	Pendleton Experiment Station: I	167	M.M. Oveson, T.R. Horning, C.J. Gerard, C.M. Smith & L.K. Beutler
1957	Pendleton Experiment Station: II	49	L.K. Beutler & K.G. Woodward
1958	Pendleton Experiment Station	131	M.M. Oveson, T.R. Horning & L.H. Beutler
1959	Pendleton Experiment Station	167	M.M. Oveson, T.R. Horning & L.H. Beutler
1960	Pendleton Experiment Station	151	M.M. Oveson & L.H. Beutler
1961	Pendleton Experiment Station	151	M.M. Oveson & L.H. Beutler
1962	Pendleton Experiment Station	157	M.M. Oveson & L.H. Beutler
1963	Pendleton Experiment Station	129	M.M. Oveson & L.H. Beutler
1964	Pendleton Experiment Station	99	M.M. Oveson, W.R. DeWitt & M.L. Jones
1965	Pendleton Experiment Station	95	M.M. Oveson, W.R. DeWitt & M.L. Jones
1966	Pendleton Experiment Station	80	M.M. Oveson, W.R. DeWitt & M.L. Jones
1967	Pendleton Experiment Station, including cereal breeding	239	C.R. Rohde, R.S. Atkinson, W.R. DeWitt, M.L. Jones, Mrs. S. Nuxall & Mrs. M.L. Hibbard

1968	Pendleton Experiment Station, including cereal breeding	230	C.R. Rohde, R.K. Schwanke. R.S. Atkinson, W.R. DeWitt, M.L. Jones, Mrs. S. Nuxall & Mrs. M.L. Hibbard
1969	Pendleton Experiment Station, including cereal breeding	234	C.R. Rohde, R.K. Schwanke. R.S. Atkinson, F. Ball, M.L. Jones, Mrs. S. Nuxall & Mrs. M.L. Hibbard
1970	Pendleton Experiment Station, including cereal breeding	239	C.R. Rohde, R.S. Atkinson, F. Ball, M.L. Jones, Mrs. S. Nuxall & Mrs. M.L. Hibbard
1971	Pendleton Experiment Station, including cereal breeding	267	C.R. Rohde, R.S. Atkinson, F. Ball, M.L. Jones, Mrs. N. Carter, Mrs. D. Ellinger & Mrs. M.L. Hibbard
1972	Pendleton Experiment Station, including cereal breeding	320	C.R. Rohde, M.F. Kolding, F. Ball, M.L. Jones & Mrs. D.E. Gibbs
1973	Pendleton Experiment Station, including cereal breeding.	316	C.R. Rohde, R.S. Atkinson, M.F. Kolding, D.J. Rydrych, F. Ball, M.L. Jones, Mrs. C.L. Brown & Mrs. D.E. Gibbs
1974	Pendleton Experiment Station, including cereal breeding	280	C.R. Rohde, W.B. Locke, F. Ball, M.L. Jones, Mrs. C.L. Brown & Mrs. D.E. Gibbs
1975	Pendleton Experiment Station, including cereal breeding	299	S. Lund, C.R. Rohde, W.B. Locke, F. Ball, M.L. Jones, Mrs. C.L. Brown & Mrs. G. Eidam
1976	Pendleton Experiment Station, including cereal breeding	275	S. Lund, C.R. Rohde, W.B. Locke, F. Ball, M.L. Jones & Mrs. G. Eidam
1931	**Cereal Breeding & Testing**	103	J.F. Martin
1932	Cereal Breeding & Testing	111	J.F. Martin
1933	Cereal Breeding & Testing	114	J.F. Martin
1934	Cereal Breeding & Testing	128	J.F. Martin
1935	Cereal Breeding & Testing	127	J.F. Martin
1936	Cereal Breeding & Testing	114	J.F. Martin
1937	Cereal Breeding & Testing	117	J.F. Martin
1938	Cereal Breeding & Testing at Pendleton and Moro	255	J.F. Martin, R.W. Henderson (Moro) & M.M. Oveson
1939	Cereal Breeding & Testing at Pendleton and Moro	250	J.F. Martin, R.W. Henderson (Moro) & M.M. Oveson
1940	Cereal Breeding & Testing at Pendleton and Moro	258	J.F. Martin, M.M. Oveson & R.W. Henderson (Moro)
1941	Cereal Breeding & Testing at Pendleton and Moro	312	J.F. Martin, M.M. Oveson & L. Hubbard (Moro)
1942	Cereal Breeding & Testing	89	J.F. Martin
1943	Cereal Breeding & Testing	69	J.T. McDermid
1944	Cereal Breeding & Testing	51	O.A. Vogel (for J.T. McDermid, who was drafted into Army)
1945	Cereal Breeding & Testing	47	J.F. Martin
1946	Cereal Breeding & Testing	44	O.A. Vogel & G.A. Mitchell
1947	Cereal Breeding & Testing	66	F.H. McNeal
1948	Cereal Breeding & Testing	77	F.H. McNeal & O.A. Vogel
1949	Cereal Breeding & Testing		(missing)
1950	Cereal Breeding & Testing	14	O.A. Vogel
1951	Cereal Breeding & Testing	22	O.A. Vogel
1951	Cereal Breeding & Testing	59	C.R. Rohde (for O.A. Vogel, W.H. Foote & C.S. Holton)
1952	Cereal Breeding & Testing	71	C.R. Rohde
1953	Cereal Breeding & Testing	134	C.R. Rohde
1954	Cereal Breeding & Testing	145	C.R. Rohde & D.W. George
1955	Cereal Breeding & Testing	221	C.R. Rohde & D.W. George
1956	Cereal Breeding & Testing	286	C.R. Rohde & D.W. George
1956	Cereal Testing	70	D.W. George
1957	Cereal Breeding & Testing	306	C.R. Rohde, D.W. George & R.S. Atkinson
1957	Cereal Testing		(missing)
1958	Cereal Breeding & Testing	269	C.R. Rohde, D.W. George & R.S. Atkinson

1958	Cereal Testing	56	D.W. George
1959	Cereal Breeding & Testing	273	C.R. Rohde, D.W. George & R.S. Atkinson
1959	Cereal Testing	72	D.W. George
1960	Cereal Breeding & Testing	270	C.R. Rohde & R.S. Atkinson
1960	Cereal Testing	236	D.W. George
1961	Cereal Breeding & Testing	243	C.R. Rohde & R.S. Atkinson
1961	Cereal Testing	226	D.W. George
1962	Cereal Breeding & Testing	149	C.R. Rohde & R.S. Atkinson
1962	Cereal Testing	63	D.W. George
1963	Cereal Breeding & Testing	156	C.R. Rohde & R.S. Atkinson
1963	Cereal Testing	42	D.W. George
1964	Cereal Breeding & Testing	139	C.R. Rohde & R.S. Atkinson
1964	Cereal Testing	42	D.W. George
1965	Cereal Breeding & Testing	158	C.R. Rohde & R.S. Atkinson
1966	Cereal Breeding & Testing	171	C.R. Rohde & R.S. Atkinson
1967-1976	Cereal breeding reports were included with main station reports		
1951	**Pendleton Erosion & Equipment**	83	M.M. Oveson, T.R. Horning & C.H. Ramage
1952	Pendleton Erosion & Equipment	191	M.M. Oveson, T.R. Horning, H.M. Waddoups & C.H. Ramage
1953	Pendleton Erosion & Equipment	206	M.M. Oveson, T.R. Horning & H.M. Waddoups
1953	**Weed Investigations**	27	D.E. Bayer
1954	Weed Investigations	68	D.E. Bayer
1955	Weed Investigations	68	D.G. Swan
1956	Weed Investigations	87	D.G. Swan
1957	Weed Investigations	99	D.G. Swan
1958	Weed Investigations	126	D.G. Swan
1959	Weed Investigations	99	D.G. Swan
1959	Weed Investigations - Appendix	48	D.G. Swan
1960	Weed Investigations	98	D.G. Swan
1961	Weed Investigations	51	D.G. Swan
1962	Weed Investigations	90	A.P. Appleby
1963	Weed Investigations	141	A.P. Appleby
1964	Weed Investigations	115	D.G. Swan
1965	Weed Investigations	82	D.J. Rydrych
1966	Weed Investigations		(missing)
1967	Weed Investigations	109	D.J. Rydrych
1968	Weed Investigations		(missing)
1969	Weed Investigations	104	D.J. Rydrych
1970	Weed Investigations	110	D.J. Rydrych
1971	Weed Investigations	115	D.J. Rydrych
1972	Weed Investigations		D.J. Rydrych
1973	Weed Investigations		D.J. Rydrych
1974	Weed Investigations		D.J. Rydrych
1975	Weed Investigations		D.J. Rydrych
1976	Weed Investigations		D.J. Rydrych
1977	Weed Investigations		D.J. Rydrych
1978	Weed Investigations		D.J. Rydrych
1979	Weed Investigations		D.J. Rydrych
1980	Weed Investigations		D.J. Rydrych
1981	Weed Investigations		D.J. Rydrych
1982	Weed Investigations		D.J. Rydrych
1983	Weed Investigations		D.J. Rydrych
1984	Weed Investigations		D.J. Rydrych
1985	Weed Investigations		D.J. Rydrych
1986	Weed Investigations		D.J. Rydrych
1987	Weed Investigations		D.J. Rydrych
1988	Weed Investigations		D.J. Rydrych
1989	Weed Investigations		D.J. Rydrych

1991	Eastern Oregon Weed Control Research Report	18	D.A. Ball
1992	EO Weed Control Res. Report	61	D.A. Ball
1993	EO Weed Control Res. Report	75	D.A. Ball
1994	EO Weed Control Res. Report	63	D.A. Ball & D.L. Walenta
1995	EO Weed Control Res. Report	71	D.A. Ball & D.L. Walenta
1996	EO Weed Control Res. Report	77	D.A. Ball & D.L. Walenta
1997	EO Weed Control Res. Report	177	D.A. Ball, D.L. Walenta & D. Singh
1998	EO Weed Control Res. Report	119	D.A. Ball, D. Singh, D.L. Walenta & G. Harris
1999	EO Weed Control Res. Report	187	D.A. Ball, D. Singh & G. Harris
2000	EO Weed Control Res. Report	207	D.A. Ball & D. Singh
2001	EO Weed Control Res. Report	126	D.A. Ball and J. Patmore
2002	EO Weed Control Res. Report	165	D.A. Ball, L.H. Bennett & S.M. Frost
2003	EO Weed Control Res. Report	143	D.A. Ball, L.H. Bennett & S.M. Frost
2004	EO Weed Control Res. Report	134	D.A. Ball, L.H. Bennett & S.M. Frost
2005	EO Weed Control Res. Report	148	D.A. Ball, L.H. Bennett & S.M. Frost
2006	EO Weed Control Res. Report	102	D.A. Ball, L.H. Bennett & S.M. Frost
2007	EO Weed Control Res. Report	170	D.A. Ball & L.H. Bennett
2008	EO Weed Control Res. Report	201	D.A. Ball & L.H. Bennett
2009	EO Weed Control Res. Report	176	D.A. Ball & L.H. Bennett
2010	EO Weed Control Res. Report	91	D.A. Ball & L.H. Bennett
1962	**Potential New Crops**	83	L.K. Beutler
1969	**Irrigation Investigations**	73	R.K. Schwanke
1970	Irrigation Investigations	24	F.V. Pumphrey
1971	Irrigation Investigations	41	F.V. Pumphrey
1972	Irrigation Investigations	55	F.V. Pumphrey
1956	**Soil & Water Cons. Res. Div.**	61	A.S. Hunter, D.L. Carter & C.J. Gerard
1957	Soil & Water Cons. Res. Div.	52	J.L. Young, D.L. Carter, A.S. Hunter & C.J. Gerard
1958	Soil & Water Cons. Res. Div.	149	C.M. Smith, T.R. Horning & M.M. Oveson
1959	Soil & Water Cons. Res. Div.	62	C.M. Smith, T.R. Horning & M.M. Oveson
1960	Soil & Water Cons. Res. Div.	109	C.M. Smith, T.R. Horning & M.M. Oveson
1961	Soil & Water Cons. Res. Div.	51	R.E. Ramig, T.R. Horning, C.M. Smith & M.M. Oveson
1962	Soil & Water Cons. Res. Div.	71	R.E. Ramig, T.R. Horning & M.M. Oveson
1963	Soil & Water Cons. Res. Div.	79	R.E. Ramig & T.R. Horning
1964	Soil & Water Cons. Res. Div.	67	R.E. Ramig & T.R. Horning
1965	Soil & Water Cons. Res. Div.	69	R.E. Ramig
1966	Soil & Water Cons. Res. Div.	74	R.E. Ramig
1967	Soil & Water Cons. Res. Div.	65	R.E. Ramig
1968	Soil & Water Cons. Res. Div.	59	R.E. Ramig
1969	Soil & Water Cons. Res. Div.	75	R.E. Ramig
1970	Columbia Plateau Cons. Res. Ctr.	80	R.E. Ramig, R.W. Rickman, L.G. Ekin & M.L. Hibbard
1971	Columbia Plateau Cons. Res. Ctr.	52	R.E. Ramig, R.R. Allmaras, P.E. Rasmussen, R.W. Rickman, L.G. Ekin & M.L. Hibbard

Appendix 7 – Determining Site for Oregon's First Dryland Station (1909)

R E P O R T ON LOCATION OF EASTERN OREGON DRY FARMING EXPERIMENT STATION

-by-
H. D. Scudder, Agronomist, Oregon Agricultural College,
and
W. M. Jardine, Agronomist in Charge of Experiments with Dry Land Grains, U. S. Department of Agriculture.

Investigations of April and May, 1909

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Corvallis, Oregon, May 15, 1909.

To the Board of Regents,

Oregon Agricultural College,

In pursuance of an enactment of the recent state Legislature (Senate Bill No. 85, filed Feb. 17, 1909), entitled "An Act to Appropriate $2500 annually for the Maintenance of an Experiment Station of the State Agricultural College on Dry, Arid, or Non-irrigated Lands in the state of Oregon," in cooperation with the United states Department of Agriculture, your committee, consisting of a representative of the United states Department of Agriculture and a representative of the Oregon Agricultural College, appointed to make investigations and recommendations concerning the location of said experiment station, beg leave to submit the following report:

NEED OF A DEMONSTRATION FARM.

It will be observed from the attached precipitation chart that the strictly dry land areas of the State of Oregon lie east of the Cascades. For thirty years or more, parts of this area have been producing large wheat crops and considerable livestock, but a point now seems to have been reached where production no longer increases. It is the unanimous feeling among all the better farmers of this region that this condition is due largely to the fact that the land now farmed is not producing what it should, and that in addition there is a vast area yet untouched by the plow that is capable of large production if the proper methods of farming were used. Even the most successful farmers of the region believe that production can be greatly increased, both on the land now farmed and on new lands that would be opened to settlement, by the introduction of better varieties of grain, the use of more thorough tillage, a wider understanding of modern dry farming practices, and a greater diversification in the crops produced.

Yet the farmers themselves cannot afford either the time or expense required to experiment with these things when it would often mean exposing themselves to the risk of losing a crop. Nor if they did experiment would their results be made much use of. The truth of this is fully demonstrate by the fact that there is practically not a single locality in all this great region where there are not now one or more farmers using many of the right methods and growing many of the right crops, on a fairly intensive scale, and with a success that should be widely followed, yet is not. Hence the universal sentiment among the people of Eastern Oregon demanding a state and government station where all of these best methods may be fully demonstrated and the results issued from an authoritative source.

The most striking need of a demonstration of better or more intensive methods of farming is found on the land already farmed. The large size of the farms, together with the continuous grain cropping on the extensive scale and the practices associated therewith, is reducing the fertility of the soil at such an alarming rate as to seriously threaten the permanency of the agriculture of this entire region. At present this decrease in fertility is not apparent to the casual eye, owing to the great virgin richness of the soil and to the better seed and better tillage used of late years, so that the yields still hold up or are even increased in some localities, over what was obtained in former years. Yet the discriminating can detect even now the effect of this destructive method of farming, in such indications as the alarming increase in the foulness of the land with weeds, the great decrease in the humus content of the soil and the steadily augmenting amount of tillage required to bring the soil back into proper physical condition after each additional cropping.

But this, however, is not the only harmful result of the extensive system of farming common to this region. Perhaps the greatest peril that Eastern Oregon has to face is the actual decrease in population in some of her oldest and best farming areas. This result can be traced directly to the condition mentioned above. In the first place, many of the largest land holders are not permanent residents and the money the land produces is taken out of the country instead of remaining there to develop it. In the second place, this system of farming deters newcomers from settling in this region, not only because this style of farming is widely different from the kind the majority of incoming settlers are used to, but because of the large amount of capital necessarily involved. Coming from the east where more intensive farming and a greater diversity of crops are the common practices, they find this extensive, one cropping system beyond their means or inclination.

In addition to this, the man of small means who does settle, must undertake the rather precarious business of renting, and renters, as a rule, do not build up a country.

The sentiment of the entire region is to the effect that this condition of large farms and small population is bad and undesirable, but that it can be best remedied, although only slowly of course, by an authoritative demonstration of the possibility of more intensive farming such as might be brought about as follows:

By the introduction of better varieties of grain,
By the improvement of methods of tillage and seeding, particularly those related to
better moisture conservation,
By the reduction of the area lying idle in summer fallow each year,
By the introduction of forage and seed crops to replace as far as possible the summer fallow,
By the accompanying introduction of more livestock on the farms,
By the rotations of crops which this greater variety of plants and animals would permit,
By the consequent increase in soil fertility and production per acre,
By the greater attractiveness in itself of this style of farming and the greater profits thereof.

That more intensive farming could be engendered in those ways, is the belief of your committee. This belief is founded not only on what is being done in every other dry farming area of the country (in many cases where conditions are not as favorable as here), but also upon what is being done by individuals in many parts of this region itself.

If then, a demonstration farm would assist in bringing about more intensive farming, there is no question that this in turn would cause production to be increased and put upon a permanent basis; the fertility of the soil to be maintained; the size of the farms reduced; population increased; and the money produced in the country retained there to build up the region in which it is made, for it is the contented small farmer that stays at home and develops a permanent and attractive agriculture.

And as for ultimate production, it does not seem too much to say that on the approximate million acres of dry land now tilled in Eastern Oregon, the total agricultural production might be increased one half; and as rapidly as transportation facilities permit, a million acres more of dry land now untilled might be brought into production.

FACTORS CONSIDERED IN SELECTING THE FARM SITE

The establishment and maintenance of this demonstration farm being a joint state and federal enterprise, it is strongly felt by your committee that above everything else the station should be so located as to do the greatest number of people the greatest possible good. To accomplish this result it is considered as essential:

FIRST - That the farm be located where it would bring most quickly, valuable and permanent results, so that it would give assistance to the farmers in the shortest possible time and so that its immediate success would lead to the establishment of farms of similar character in other localities where the need of them is felt.

SECOND - That the farm be located under soil and climatic conditions representative of the actual conditions under which the great majority of the farming in this region is now done.

The idea that it would be desirable to locate this farm under the most extreme conditions of soil and climate to be found, and if successful there, its methods would be successful anywhere else, is not concurred in by your committee. In the first place, it is believed, as has been suggested heretofore, that this farm should be run on such a money-making basis as would demonstrate the possibility of profitable agriculture on the three hundred twenty acre farm unit. There is a large area having the extreme conditions above mentioned where no farming is being done or where no permanent dry farming on a three hundred twenty acre basis ever will be done. Secondly, methods used under extreme conditions differ very widely from those used under the more moderate conditions which prevail over most of the Eastern Oregon area now farmed, hence demonstrations worked out under extreme conditions would in no way fit the great bulk of the genuine farming interests of this region. Thirdly, if this station is to be a true demonstration farm, it must demonstrate the possibility of more successful agriculture with the same and the real conditions under which the farmers looking for assistance are actually working, not with extreme or hypothetical conditions under which farmers will never be called upon to struggle.

THIRD - That the farm be placed in the midst of an area where the destructive effects of the extensive method of farming large holdings are most prevalent, thus making more striking a demonstration of the permanent profits of the more intensive and constructive methods under the same conditions.

FOURTH - That the farm be located where it could be easily viewed and widely pointed out from some main artery of travel, so as to attract attention not only from the present inhabitants of all this region, but also from newcomers, so that its appearance might encourage settlement.

FIFTH - That it be located where it would be most readily accessible, both from the standpoint of time and expense. The success of any demonstration depends considerably upon the number of interested visitors who see the results accomplished, with their own eyes. The difference of an extra half-day's travel and expense night be sufficient in many cases to deter farmers from visiting the station as frequently and freely as is desirable for its greatest success.

SIXTH - That it be located in a community of such progressive and cooperative spirit and keen interest as would make the greatest use of the results obtained; or where there would be such an agricultural organization as would bring in people from other parts of the same region or newcomers from outside; or would help to spread broadcast, by word and example, the successful methods that may be developed at this station.

TERRITORY EXAMINED.

After a careful study end preliminary investigation and survey of the entire dry land area of the State, lying east of the Cascades, it was found that there are two great areas in which dry farming will always be the paramount agricultural issue. These two areas are:

1. The region surrounding and tributary to Harney County, consisting mainly of the northern two-thirds of Harney County itself, with the small portions of Lake, Crook, Grant and Malheur counties immediately adjoining this specified part of Harney County. (See attached map).
2. The region surrounding and tributary to the great wheat belt of Sherman, Gilliam and Morrow Counties, consisting mainly of these three counties themselves and the east one-half of Wasco, the north-west one-fourth of Crook and portions of Wheeler County. (See attached map).

These two general and widely separated areas were selected as superior to all other parts of the state in that they are the two largest and most important, and most typical dry land areas that lie with their respective parts contiguous, thus presenting all such features as would make the service of a dry farming demonstration station most productive of results and most feasible of establishment. Hence these two areas were given a more detailed examination to determine upon such definite location of this station as should bring the greatest results.

Briefly stated, the reasons that the other portions of Eastern Oregon were not included in the areas selected for final consideration as to location of this station, are that one or more of the following conditions were found to prevail in them, making them unsuitable for a dry farming station with the purposes hereinbefore outlined, namely:

1. Too great a rainfall.
2. Agricultural land s devoted largely to irrigation farming, or naturally sub-irrigated.
3. Too mountainous in character.
4. Soil conditions not in any way typical of the entire area.
5. Agricultural lands largely small valleys capable of irrigation.
6. Relatively little dry farming done or possible.
7. Prohibitive inaccessibility to the rest of the region.
8. Dry Land area rocky or shallow soiled, extremely alkaline, extremely arid , or soil of no value chemically.

While there are limited areas in nearly all of these counties that would be greatly benefited by a dry farming station, yet their claims for the station, as can be readily seen, in no way compare with those of the two great dry land areas selected, these latter having practically no other resource for general agricultural success except through dry farming.

METHOD OF EXAMINATION.

The method of investigation was carefully planned beforehand, routes mapped and regions to be visited notified, so that the progress of the work was rapid and yet was carried out with all possible accuracy and with extreme care to secure all data that might have any bearing on the case. All the main centers of agricultural population in the two areas were visited; public meetings were held with the people of each locality; the requirements and proposed work of the station were fully explained; the conditions, advantages and needs of each locality were then fully set forth by the numerous leading farmers and business men of each section; authoritative statistics were secured; conveyances were then obtained and practically all the main agricultural areas of each section carefully surveyed; the soil and crops critically examined and sampled, and on every occasion, expressions as to the conditions of the proposed work, secured directly from the men on the land themselves. Before leaving any region, possible station sites were minutely examined and noted and written propositions from the County Courts as to what assistance could be given, were obtained.

In this connection, your Committee wishes to take the opportunity to state that the splendid spirit of broadminded fairness shown towards this project by the citizens in every part of all of the region visited, should receive the highest commendation. The most cordial reception was given the proposed undertaking on every hand and no effort was spared to assist in forwarding the thoroughness of the investigation. Everywhere the vital need of this work was fully appreciated by the wide-awake men of this region. It is especially worthy of note that in no case did the people of any single locality fail to express their willingness to support or assist the station in every way possible even if it were not located in their immediate vicinity.

(NOTE.--The investigation of the two areas selected was interrupted by the enforced return of Mr. Jardine to Washington, D. C., and on his being unable to resume the work, at his suggestion, the Harney area was examined by the other member of the Committee accompanied by Professor C. E. Bradley of the Oregon Agricultural College, the necessary data obtained, submitted to Mr. Jardine and incorporated into this report.)

(NOTE. – The assistance required from the area in which the station is to be located, was estimated to be at least, the purchase of twenty year lease of two hundred acres of land and six thousand dollars for improvements and initial equipment, and was so stated to the various communities visited.)

DISCUSSION OF CONDITIONS IN THE TWO AREAS.

In so short a report as this it is impossible to include all of the data secured regarding the conditions observed in these two great areas. Only the most important evidence bearing directly upon the case in hand can be admitted. It does not seem best to attempt in this report to meet all the arguments that may be advanced for or against either one of these areas.

THE HARNEY AREA.

The total area of this district as shown on the attached map, approximates five million acres of which about two million acres are estimated tillable, the remainder being grazing or waste land. Of the tillable land less than one-twentieth or about seventy-three thousand acres is now in cultivation, mainly under irrigation. Of the total tillable land a conservative estimate would place one million acres as susceptible of successful dry farming, yet not now tilled; about four hundred thousand acres more capable of irrigation; and the remainder of too thin or poor a soil to be of value.

The soil of the dry farming portion of this area, is, in the main, excellent, being for the most part a dark brown alluvial sandy loam, somewhat alkaline where poorly drained. This soil is of desirable depth throughout the great, nearly level valley areas, becoming richer in all of the slight swales and more heavy and less deep on the rolling lands. The heavy growth of large black sage indicates the soil to be rich in plant foods, analysis showing it to be of good nitrogen, potash and lime content but somewhat low in phosphorus. Altogether it is a soil capable of high production.

The agriculture of this area is now almost wholly confined to stock raising, there being about six thousand horses and mules, fifty thousand cattle, six hundred thousand sheep and five hundred hogs in Harney County, alone last year, which would approximate the total amount in the area under discussion. The remaining production of the area consists chiefly of some seventy thousand tons of hay, (some of it alfalfa) and some barley and oats, all used for feeding; the limited amount of wheat needed to supply the local mill; and fruit and vegetables for local consumption. Nearly all of the production above named is accomplished through irrigation; the yields of all these crops being high and of most excellent quality.

As for dry farming production, there is practically none in this area, of the seventy-three thousand acres cultivated, seventy thousand being irrigated, largely form the winter overflow of streams or private ditches. That the possibilities for dry farming are immense, however, there is no question. Mr. I. S. Goer, whose efforts in this direction are to be highly commended, has made an excellent beginning in testing the possibilities for dry farming in this area; sufficient to indicate the success with which this may be done. Wheat, barley, rye and other crops have also been produced in limited quantities on dry land by several other farmers in Harney Valley, the yields being excellent, even though in most cases the varieties used were not the best.

The general elevation of this area is from four thousand to five thousand feet and the occurrence of frosts not of such character as to deter dry farming. The annual rainfall averages ten inches, sometimes being as high as fifteen inches; its amount and distribution we believe sufficient for profitable dry farming.

The population of this area, as shown by the census of 1900, is about three thousand and is estimated now at from four thousand to four thousand five hundred and of whom about one thousand five hundred are found in towns. The city of Burns of one thousand inhabitants is the only place of any size.

About sixty per cent of the assessed land of the area is owned by nonresidents, chiefly large livestock or road companies. The selling price of unimproved land suitable for dry farming is from $5 to $10 per acre.

At present this entire area is shut off from transportation facilities, the nearest branch of the railroad being over one hundred miles distant over very mountainous roads, too difficult to permit hauling agricultural produce, hence the prevalency of stock raising. Perhaps no where else in the United States is these so large a body of land lying idle, waiting for a railroad and the hand of the dry farmer to transform it from a desert to prosperous production. Yet there is perhaps no other unserved area where, from the agricultural standpoint at least, a railroad would prove more profitable. Here lies in this area alone two million acres of grazing land, a million acres of wheat land, and a half million acres of rich irrigation land – one of the great agricultural districts of the future.

The attitude of the people of this area toward the dry farming project is one of great eagerness. Having had little experience in dry farming methods and crops to guide them, they feel keenly the need of assistance in tackling a practically untouched problem and as may be seen by the attached proposition of the Harney County court, they offer every facility required for the establishment of a demonstration farm.

THE WHEAT BELT AREA.

Approximately three million acres of land are comprised in this area (see attached map), of which fully two million acres are tillable and seven hundred fifty thousand acres now in cultivation, the remainder being grazing and waste land. Practically all of this area comes under dry farming conditions, there being almost no irrigation. Of the two million acres of tillable land, fully one million five hundred thousand acres are susceptible of successful dry farming, the cultivated land above named being so farmed now.

The soil of this area is in the main a dark gray silt loam of great excellence, especially adapted physically for dry farming tillage and rich in plant food, but decreasing steadily in humus content from continuous extensive wheat farming and associated bad tillage. Throughout this area the soil varies uniformly from a lighter sandier type of silt loam in the northern part to a heavier richer silt loam in the southern part of the area. This change in the soil is associated with the same change that is found to occur in the rainfall and the elevation, both of which increase as one travels south; the rainfall from 5 inches annually along the Columbia to 15 inches at the southern boundary of the area, and the elevation from 300 feet to 4000 feet. In any of the four counties Wasco, Sherman, Gilliam, and Morrow, an average of the conditions of soil, rainfall and elevation for the whole area may be found approximately half way from the north to the south. The only exception to this is a slight variation of soil from the west to the east, the soil of Sherman County as a whole being slightly heavier and as a rule deeper than that in Gilliam, and that of Gilliam the same as compared to that of Morrow. The depth of soil in the wheat section of Sherman county will average six feet, in Gilliam four feet, and in Morrow two feet. The greatest variations in soil in any one part of the area was found in Sherman County. In the district extending from Gordon Ridge to Nigger Ridge rich silt loam and sandy silt loam, deep, shallow, and so-called scabby land were often found on very limited areas, side by side.

Counties	SHERMAN	GILLIAM	MORROW	Portions of WASCO, CROOK, & WHEELER	TOTALS
Population	3,000	5,500	5,500	500	14,500
Cultivated acreage	260,000	225,000	200,000	100,000	785,000
Av. price per acre	$25	$20	$20		
Tillable acreage	300,000	500,000	875,000	300,000	1,975,000
Wheat produced '07	2,500,000	2,500,000	2,600,000	2,000,000	7,100,000
Av. yield per acre	20	20	20		
No. of horses '08	6,349	5,582	4,619	6,000	22,550
" " cattle "	1,951	4,251	4,731	20,000	30,933
" " sheep "	8,413	61,094	149,645	100,000	319,152
" " hogs "	1,561	1,823	1,366	500	5,250

A corresponding change is found in the size of farms:

Counties		SHERMAN	MORROW
Farms between	640 – 1000 A. in size	50%	66%
" "	1,000 – 2000 " " "	34%	28%
" "	2,000 – 5000 " " "	16%	6%

Dry farming produces practically all of the crops in this area, these being mainly wheat, barley, and oats. A limited amount of irrigation in the narrow creek bottoms produces considerable alfalfa. Agricultural statistics, closely approximated, for the area are given by counties in the table.Noticeable in the table is the decrease in cultivated area and wheat production and the increase in stock raising as one travels east from Sherman County.

An illustration of the lack of intensive farming is the almost negligible number of hogs found in this area, although thousands of carloads of these animals are annually shipped to this state from the middle west.

Another interesting comparison between the western and eastern parts of this area is in the number of combined harvesters and threshers being used, 146 of these machines in Sherman County as against fifteen in Morrow. These machines are symbolical of the extensive or destructive system of farming.

As an illustration of the startling rapidity with which money produced in this area leaves the country following the wheat harvests, one banker in Sherman County states that in a single month after harvest, deposits dropped from $700,000 to $100,000.

The population of the area totals approximately 14,500 people, four-fifths of whom live outside of the towns. In Gilliam and Morrow counties the population has been almost at a standstill for the last five years, increasing only very slightly, while in Sherman the population has decreased from 4,000 to 3,000 in the last four years. In this latter county, 50% to 60% of all the land is owned by men living outside of the county--the resident taxpayers owning about one-third of the property of the county.

The transportation facilities in this area are very fair, each of the three counties having a branch line of the railroad. Twenty mile hauls are not uncommon and on account of the topography of the country, even with further railroad extension, a certain amount of long distance hauling will always have to be done.

As elsewhere in Eastern Oregon, the people of this area feel keenly the need of a demonstration farm. An agricultural organization to forward this work is being perfected throughout the area, the oldest and strongest being in Sherman County. Each county has offered every assistance required to establish the station, as may be seen by the attached proposition of the prospective county courts.

COMPARISONS AND RECOMMENDATIONS

The relative needs of these two great areas for the demonstration station are about equal. The chief difference between them is in the character of their needs.

As is shown heretofore, in the Harney area the pressing need of the station is to develop new territory, while in the wheat belt area the equally pressing need is to make agricultural production permanent.

Of the two, the latter is unquestionably more dependent upon a demonstration farm than is the former area. Although the Harney area has great need of the station to introduce the best methods for development, yet development is dependent primarily and above everything else on the advent of a railroad. Farmers will not enter this territory and engage in dry farming, no matter how successful it may be demonstrated to be, unless there is a railroad to carry away the products. Until transportation facilities are obtained, no matter how large dry farming production might be, dry farming would be an utter failure if there were no sale for such products. While it seems hard to deny this community the station because of the lack of a railroad, when it is this very lack from which they already suffer most--yet such are the indisputable facts in the case.

In further comparison of the areas it may be added that the Harney area may still do much for itself in the way of dry farming without assistance, as other regions have done before it, while the wheat belt area has reached a point where it has done practically all it can do for itself and now has no other recourse but the assistance possible to be gained from a demonstration station in the manner already described. It is dependent upon this assistance not only for further development, but for the very permanency of its existence.

In addition to this, considered from the standpoint of all the dry land regions of Eastern Oregon, the results obtained from demonstrations and experiments carried on in the wheat belt area will apply to practically all dry land areas in the state (even in Harney County itself, notwithstanding a slight difference in elevation) much better than would be the case if the locations were reversed. This would still be true if the only factor considered was the great inaccessibility of the Harney area to people of the rest of the State.

In addition to this a much greater number of people will be benefited by a station in the wheat belt, not only in this area itself, but throughout Eastern Oregon. This is true not only because of the many thousands engaged in dry farming in this areas as compared with practically none now so engaged in the Harney area, but also because a station in the wheat belt would attract more attention and bring quicker results, thus leading to the establishment of further stations.

As to the most desirable part of the wheat belt area for the site of the station, it is believed that that the location of the same in the Moro district in Sherman county will unquestionably afford more typical and favorable conditions for a dry farming demonstration fitted to the greatest needs of the entire eastern half of the state, than any other locality therein, and for this reason the United States Department of Agriculture desires, to have the Station located in this district.

The station if located here would do the greatest number of people the greatest possible good for the following reasons:

1. Soil conditions may be found here on a single half section of land that typify practically every condition found in the entire wheat belt area: light sandy silt loam or heavier or average type; deep or shallow, and any slope--while the rainfall (9 inches) and the elevation (2,000 feet) are also precisely the average under which all the dry farming of the area is being done.
2. This district is also in the midst of the worst conditions to be found as regards the destructive extensive system of farming, upon the remedy of which the future prosperity of all Eastern Oregon depends. While the average rainfall and elevation conditions could be secured on sites in Gilliam and Morrow Counties, such typical soil conditions could not be found.
3. The district is the most centrally located of any in the area. All of the great dry farming area to the west and the south along the Deschutes River in Wasco and Crook counties, as well as all of Sherman County itself are immediately tributary, with conditions all similar to this district. On the other hand, in both Gilliam and Morrow counties the farming land is abruptly cut off on the south by the western spurs of the Blue Mountains, and on the east by the irrigated country of the Umatilla.
4. This location is the more accessible and would attract and receive more attention than any other. The current travel in eastern Oregon as elsewhere is down the rivers to Portland. This district lying at the confluence of the Deschutes and Columbia, with the branch and main line of the railroad paralleling these rivers, gets more passenger traffic than any other section. Whereas Wasco, Sherman and Crook county farmers would have to make journeys entirely out of their way if the station were located in Gilliam or Morrow counties—the farmers in the latter counties or to the south and west of Moro need only stop off on the way to Portland to visit the station. Public roads and bridges also connect this district to the regions on all sides.
5. In addition to the site selected here lies just west of the town of Moro, sloping down and bounded on its eastern edge (see map) by the railroad, so that the entire tract is visible from the trains or the town. In addition it is bounded on the south by the main travelled road, and is but ten minutes walk from Moro itself, which town is the county seat and has many visitors.
6. Finally, because of the numerous conditions already mentioned, it is believed that results will be obtained more quickly here than elsewhere.

Hence having investigated conditions fully and impartially, and viewed the matter most carefully from every standpoint, your committee strongly recommends the establishment of the first Eastern Oregon dry farming station on the site selected at Moro.

Your committee also recommends, since wherever located, this station cannot fully satisfy the needs of ell districts, that that an far as possible cooperative work be done and other stations of this character be established as quickly as practicable, to assist the dry farmers in the regions more remote and less well served.

Respectfully submitted, __________________________

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9/13/09

PROCEEDINGS OF THE COUNTY COURT IN CONNECTION WITH

Purchase of site for the Eastern Oregon Dry Farming Sub-Station

Upon my return from Corvallis, Oregon, where I proceeded immediately upon hearing of the decision of the Board of Regents, locating the station here at Moro, Mr. Scudder and I endeavored to have Judge Hendricks, of the County Court, call an extra session, for the purpose of purchasing the land. He declined to do this, however, as the regular session would be held in 2 ½ weeks, and he did not want it to appear that he was railroading such a proposition through without ample notice to the people of the County. Nothing was done, therefore, until the regular session, held Sept. 7. At this time, two propositions were submitted: one from the Eastern Oregon Land Company, through their agent, George W. Berrian; the other from Mr. L. Barnum, of Moro. These two propositions covered the site selected by the Committee (Professors Jardine and Scudder) in April of this year, as the first choice of any location about Moro.

The E. O. L. proposition was as follows: To sell the northeast quarter section 17 e. 1 s. for $45 per acre for the tillable land, and $10 per acre for the non-tillable (20 acres), amounting to $6500 for 160 acres. Of this amount, $100 is to be refunded by the Company to the County Court, making the total cost of the 160 acres $6400, or an average cost of $40 per acre.

L. Barnum's proposition was as follows: To sell that part of s. ½ of nw ¼ of sec. 17, lying south and east of the O. R. & N. R.R. for $4500.

On account of the absence of one member of the Court, they adjourned until the following Friday, Sept. 10, when the following action was taken: The proposition submitted by the Eastern Oregon Land Company was accepted as stated; the proposition made by Mr. Barnum was rejected. The exact number of acres he desired to sell for $4500 was not stated, and when the tract was measured, it was found to contain 74 ½ acres, exclusive of a tract known as Barnum's addition to the City of Moro. After considerable dealing, however, Mr. Barnum agreed to take $3280 for the land, which is practically $44 an acre. This was accepted.

The land is now to be leased by the County of Sherman to the State of Oregon, for experimental purposes, for a period of 20 years.

In addition to the land, a credit of $7500 was extended to me to erect buildings, purchase teams, etc.

Appendix 8 – Deeds to Land for the Sherman Station (1909)

Deeds to Two Parcels of Land Purchased by Sherman County

Know all Men by these Presents, That We E.E. Barnum and Mary E. Barnum husband and wife and L. Barnum and May Barnum husband and wife, of Moro, County of Sherman, State of Oregon, in consideration of Three Thousand Five hundred and eighty Dollars, in us paid by The County of Sherman and the State of Oregon, to wit: All that portion of the Northwest quarter of Section Seventeen (17) in Township One (1) South Range Seventeen East of Willamette Meridian, lying South and East of the right-of-way heretofore granted to the Columbia Southern Railway Company, a corporation, as now surveyed and located across said described quarter section of land, excepting a small portion of said tract in the Southwest corner thereof upon which is located Block G (G) of Barnums Addition to the town of Moro in said County and State, and the adjacent streets and alleys, dedicated to the public in connection with said addition there being of said tract so granted and hereby conveyed seventy-four acres more or less.

Together with, all and singular, the tenements, hereditaments and appurtenances thereunto belonging or in anywise appertaining and also all our estate, right, title, and interest in and to the same, including dower and claim of dower.

TO HAVE AND TO HOLD the above described and granted premises unto the said Sherman County it successors and assigns forever. And said grantors do covenant to and with said grantee its successors, and assigns, that they are lawfully seized in fee of the said premises, and have good right to sell and convey the same; that said granted premises are free from all incumbrances and that they will and their heirs, executors and administrators, shall warrant and forever defend the above granted premises and every part and parcel thereof, against the lawful claims and demands of all persons whatsoever.

IN WITNESS THEREOF we the grantors above named, hereunto set our hands and seals this 30th day of September, A.D. 1909.

Signed, sealed and delivered in the presence of

W.D. Wallan	E.E. Barnum [Seal]
W. Stanley	Mary E. Barnum [Seal]
	L. Barnum [Seal]
	May Barnum [Seal]

STATE OF OREGON
County of Sherman [ss]

This Certifies, That on this 30th day of September, A.D. 1909, before me, the undersigned Notary Public in and for the County and State, personally appeared the within named E.E. Barnum and May E. Barnum husband and wife and L. Barnum and May Barnum husband and wife who are known to me to be the identical persons described in and who executed the within instrument, and severally acknowledged to me that they executed the same freely and voluntarily for the uses and purposes thereto mentioned.

IN TESTIMONY WHEREOF, I have hereunto set my hand and Notarial seal the day and year last above written.

W. Stanley
Notary Public for Oregon [Seal]

Filed for Record at the request of __(*blank*)__ at 10 o'clock A.M. October 7th, A.D. 1909.

H.S. McDanel, County Clerk

EASTERN OREGON LAND CO. Filed for record Oct. 22, 1909 at 1. P.M.
To Sherman County, Oregon.

THIS INDENTURE, made this 5th day of October, in the year one thousand nine hundred and nine, between the EASTERN OREGON LAND COMPANY, and having its office at the City and County of San Francisco, State of California, the party of the first part, and the County of Sherman, State of Oregon, the party of the second part,

WITHNESSETH. That the said party of the first part, for and in consideration of the sum of Six thousand five hundred Dollars, Gold coin of the United States of America, to it in hand paid by the said party of the second part, the receipt whereof is hereby acknowledged, has granted, bargained, sold, alienated, remises, released, conveyed and confirmed, and by these presents does grant, bargain, sell, alienate, remise, release, convey and confirm, unto the said party of the second part, and to its successors and assigns, forever, all that certain lot, tract or parcel of land situate, lying and being in the said County of Sherman, State of Oregon, known and described as follows, to wit:

The Northeast quarter of section Seventeen (17) In township One (1) South of range Seventeen East of the Willamette Meridian, containing 160 acres more or less.

But subject always to the conditions, provisions, obligations and stipulations contained in the INDENTURE OF LEASE between said party of the first part and A.G. Boesen, by which the said party of the first part leased to him, the said A.G. Boesen, the above mentioned premises for a term commencing on October 1st, 1908 and ending Oct. 1, 1910.

Reserving and excepting of the aforesaid land, to and on behalf of the grantor herein, and its successors and assigns, the use of all the surface ground necessary to access and for the purpose of exploring, developing or working of mines or valuable underground deposits of minerals, or oils, of whatever nature, and also reserving and excepting to and on behalf of the grantor herein, and its successors, all the Gold, silver, copper, iron or minerals of whatsoever name or nature, and all the coal, mineral oils, or vegetable oils, or oils of any name or nature, or salt or saline Springs or Springs of any name or nature excepting water, which are now known to exist or hereafter many be discovered in or upon the said land.

Reserving and excepting also to the said party of the first part, and its successors and assigns, the rental share of the crop for the year One thousand nine hundred and nine due unto the said party of the first part according to the terms of the beforementioned Indenture of Lease between the said party of the first part and the said A.G. Boesen.

TOGETHER with all and singular tenements, hereditaments and appurtenances thereunto belonging or in anywise appertaining, and the reversions, remainders, rents issues and profits thereof which are not excepted or reserved herein.

TO HAVE AND TO HOLD, all and singular the said premises, together with the appurtenances unto the said party of the second part, its successors and assigns forever.

IN WITNESS WHEREOF, the said party of the first part has caused these presents to be signed in its corporate name by its President and Secretary and its Corporate seal to be hereunto affixed the day and year first above written.

Signed, sealed and delivered in The presence of EASTERN OREGON LAND COMPANY
W.T. Hess. By Walter S. Martin, President.
A.K.P. Harmon. By A.E. Wallis, Secretary.) Corporate Seal)

STATE OF CALIFORNIA City and County of San Francisco)SS:

On this 5th day of October, 1909, before me, did say that he appeared Walter S. Martin and A.E. Wallis, to me personally known, who, being each duly sworn did say that he is the President and Secretary, respectively of the Eastern Oregon Land Company, and that the seal affixed to said instrument is the corporate seal of said corporation, and that said instrument was signed and sealed in behalf of said corporation by authority of its Board of Directors, and said Walter S. Martin and A.E. Wallis, respectively acknowledged said instrument to the free act and deed of said corporation.

IN TESTIMONY WHEREOF, I have hereunto set my hand and affixed my official seal, this the day and year first in this, my certificate, written. W.T. Hess.
Notary Public in and for the City and County of San Francisco, California (SEAL)

Appendix 9 – Sherman Station's First Annual Report (1910)

COOPERATIVE GRAIN INVESTIGATIONS
EASTERN OREGON DRY-FARMING SUBSTATION, MORO, ORE.
ANNUAL REPORT OF THE SUPERINTENDENT, 1910

H. D. Scudder, Agronomist, Oregon Agricultural College, and
Owen Beaty, Foreman, Eastern Oregon Dry-Farming Substation

INTRODUCTION

In February, 1909, the Oregon Legislature appropriated an annual sum of $2500, beginning January 1, 1909, for the purpose of establishing an experiment station, in cooperation with the U.S. Department of Agriculture, on dry, arid or non-irrigated land in Oregon. The Act is quoted below:

Laws of Oregon, 1909, page 107, Chapter 61 (S.B. 85)

AN ACT

To appropriate $2,500.00 annually for the payment of the salaries of the officers and employees and for the maintenance and general and contingent expenses of conducting and maintaining an experiment station of the State Agricultural College, on dry, arid or non-irrigated lands in the State of Oregon.

WHEREAS, the United States Department of Agriculture has offered to expend the sum of not less than $2,500.00 annually to assist the State of Oregon in establishing, maintaining and supporting an agricultural experiment station on dry, arid or non-irrigated land in the State of Oregon, provided the State of Oregon shall appropriate the sum of not less than $2,500.00 for like purpose; and

WHEREAS, the people of certain sections of Eastern Oregon have offered to furnish necessary land, permanent improvements, and initial equipment for said experiment station; and

WHEREAS, in order to obtain the said assistance of the Federal Government, it will be necessary for the State of Oregon to appropriate at least the sum of $2,500.00 annually toward the establishment, maintenance, and support of said experiment station.

Now therefore,

Be it enacted by the Legislative Assembly of the State of Oregon:

Be it enacted by the people of the State of Oregon:

Section 1. That in order to investigate and demonstrate the conditions under which useful plants may be grown on dry, arid or non-irrigated lands of the State of Oregon, and to determine the kinds of plants best adapted for growth on these lands, there be, and is hereby established in the manner in this act provided, an experiment station in the State of Oregon for such purpose.

Section 2. That there be and is hereby appropriated the sum of $2,500.00 annually to assist in the payment of the salaries of officers and employees and to assist in the payment of the maintenance and general and contingent expenses of conducting the said experiment station provided for in Section 1 of this act.

Section 3. That said experiment station shall be located on such part of dry, arid or non-irrigated lands of the State of Oregon by and under the direction of the Board of Regents of the State Agricultural College of Oregon, as shall be selected by the Board of Regents of said College acting in cooperation with a representative of the United States Department of Agriculture.

Section 4. That the said station shall be under the management and control of the Board of Regents of the State Agricultural College of Oregon as a branch station of said college.

Section 5. That it shall be the duty of those having said experimental farm in charge to secure seeds from this and other countries of the world, of plants that are thought suitable for growth on dry lands, and to observe and record the growth, yield and composition of the plants grown from seeds so secured; to investigate and determine the methods of soil treatment by which the soil water is best conserved; to investigate the possibilities of grazing on dry lands which have been seeded to different crops, and to undertake such other experiments and demonstrations as may be deemed advisable, having in view the reclamation of the dry or arid lands of the State.

Section 6. That the said Board of Regents of said College shall cause to be prepared and published full and complete annual reports of the work undertaken and accomplished by said station and that an edition of such number of copies as said Board of Regents shall determine, shall be published annually and distributed free of charge, and the cost of such publication and distribution shall be deemed a part of the general expense of said station.

Section 7. That said money hereby appropriated be paid quarterly out of any moneys in the general funds of the State treasury not otherwise appropriated, commencing January 1, 1909.

Section 8. That upon requisition being made by the treasurer of the Board of Regents of the State Agricultural College, the Secretary of State shall draw a warrant upon the State Treasurer payable out of said funds for the said quarterly payments.

Section 9. The appropriation provided by the terms of this act shall not be available until the necessary land, permanent improvements and initial equipment are conveyed, without cost, to the State of Oregon, the terms of such conveyance to be to the satisfaction of the Board of Regents of said State Agricultural College. The County Court of the county in which said experiment station may be located is hereby authorized and empowered to acquire either by purchase or lease, sufficient suitable land to be selected by the Board of Regents of said Oregon Agricultural College, acting in cooperation with a representative of the United States Department of Agriculture; in case said land is acquired by a purchase the purchase price therefor shall be paid from the general funds of the county upon the order of the County Court by a warrant, in the manner in which other claims against the county are paid; in case the site for said station is acquired by lease, the lease shall be made in favor of the State of Oregon for such term of years and upon such conditions as shall be required by the Board of Regents of the Oregon Agricultural College and the rent therefor shall be paid out of the county treasury of the county in which said station is located by warrant drawn upon the county treasurer by and order by the County Court. In the event said station shall be discontinued the property acquired hereunder, including land and improvements thereon as well as improvements placed upon leased land, may be sold by the County Court in such manner and upon such terms and upon such conditions as said County Court as a regular term thereof may determine upon, and the proceeds arising from such sale shall be returned to the general funds of the county. That the County Court of the said county in which said station is located is further authorized and directed to place upon the land, acquired as aforesaid, such buildings and other improvements, including a well, as may be required by the Board of Regents of the Oregon Agricultural College and the expenses incurred thereby shall be paid in the manner above provided for the payment of the purchase price or rent of the land.

Section 10. A certificate of the president and secretary of the Board of Regents of said State Agricultural College under the seal of said college that the Federal Government has made arrangements satisfactory to said Board of Regents for the annual payment of said sum of not less than $2,500.00 from the Department of Agriculture, and that a conveyance of necessary land, permanent improvements and initial equipment satisfactory to said Board of Regents has been received, shall be sufficient authority to the Secretary of State to commence paying said money appropriated by the terms of this act to the treasurer of said college upon requisition therefor.

Section 11. In the event more than one quarter has passed before requisition is made for said money, then requisition may be made at one time for as many quarterly payments as may be due at that time and said Secretary of State shall honor and pay the same.

Filed in the office of the Secretary of State Feb. 17, 1909.

INVESTIGATION OF PROSPECTIVE STATION SITES

This law contemplated the offer of various sites in those sections where dry farming was principally conducted and it was understood that the county in which the station was located must furnish the necessary land, as well as permanent improvements and initial equipment.

In accordance with section 3, Prof. H.D. Scudder, of the Oregon Agricultural College, and Mr. W.M. Jardine, of the U.S. Department of Agriculture, proceeded in April and May, 1909, to investigate the various dry-farming sections of the state, with a view of selecting the most suitable site for the experiment station.

They wisely decided beforehand that the farm should be located where it would be most accessible to the greatest number of farmers; that it be a section having soil and climatic conditions representative of the majority of the region where dry farming was practiced; that it be in the midst of an area where the destructive effects of extensive farming of large holdings were most evident, in order to make the more striking the demonstration of the permanent profits of more intensive and constructive methods under the same system; and that it be located where the farm could be widely viewed from some main artery of travel, in order to benefit others as well as nearby residents.

A number of sections were considered, but were not closely investigated for the reason that all possessed one or more of the following features unsuitable for a dry-farming station:

1. Too great rainfall.
2. Agricultural lands devoted too largely to irrigated farming, or naturally subirrigated.
3. Too mountainous in character.
4. Soil conditions not typical of entire area.
5. Agricultural lands chiefly in small valleys capable of irrigation.
6. Relatively little dry farming done or capable of development.
7. Prohibitive inaccessibility to remainder of region.
8. Dry land area rocky or shallow soiled, extremely alkaline, extremely arid, or soil of no value chemically.

That part deemed worthy of examination lies east of the Cascade Mountains of Oregon, as does practically all the territory in which dry or irrigated farming is successfully carried on, and consists of two great areas, differing from each other so much as to constitute two classes. These are the Harney area on the South and the wheat belt area on the North. A discussion of the two areas is unnecessary in this connection, as mention of the difference is made merely to indicate why the Committee decided on the present location. This is of interest because it bears so largely on the purpose and future policy of the Station. Professor Scudder in his report to the Board of Regents writes as follows:

> As is shown heretofore in the Harney area, the pressing need of the station is to develop new territory, while in the wheat belt area the equally pressing need is to make agricultural production permanent.
>
> Of the two, the latter area is unquestionably more dependent upon a demonstration farm than the former. Although the Harney area has great need of the station, yet development is dependent primarily and above everything else on the advent of a railroad.

He points out the fact that Harney County can still do much for itself until the railroad comes, while the wheat-belt area has done for itself practically everything possible and has no resource other than assistance from the experiment station.

Another factor favorable to the selection of the wheat-belt area is that results obtained here would also apply to the Harney area. In the wheat belt the station site could also be selected along a railroad, thus benefiting a much larger number of people. In this section, it would help maintain an agriculture that was deteriorating and results secured could be applied immediately without awaiting the development of the country.

In the wheat-belt area, Sherman County seemed most desirable because the soil and climatic conditions in this section were typical of the whole area which needed a station; and also because the general travel of eastern Oregon is through, or past, that county toward Portland. A site adjacent to Moro, the county seat, was selected for the experiment station. In addition to being on a railroad, another advantage in selecting the county seat in preference to another town is that it is the one most likely to be visited at least once a year by practically every farmer and business man in the county.

INDUCEMENTS OFFERED BY SHERMAN COUNTY

When Professors Jardine and Scudder, the committee appointed to select the station site, visited Moro, the Sherman County Development League arranged a meeting with the representatives of the County and, as a result, the county promised to spend a sum not to exceed $20,000 for initial equipment, permanent improvements, and land, as required by the law creating the appropriation. The Development League men particularly active in this connection were C.A. Buckley, president of the League; Geo. Mowry, secretary;

L. Barnum, a banker at Moro; and George Berrian, agent of the Eastern Oregon Land Company.

Sherman County offered a very favorable location at Moro, and the committee, on May 15, 1909, recommended to the Board of Regents that this site be chosen. The Board of Regents approved the selection of the Committee and agreed, with the U.S. Department of Agriculture, to the following Memorandum of Understanding:

MEMORADUM OF UNDERSTANDING

BETWEEN THE OREGON AGRICULTURAL EXPERIMENT STATION AND THE BUREAU OF PLANT INDUSTRY, U.S. DEPARTMENT OF AGRICULTURE RELATIVE TO COOPERATIVE EXPERIMENTS WITH CEREALS, TO TAKE EFFECT JULY 1, 1909.

The objects of these cooperative investigations shall be (1) to improve the cereals of the Pacific Coast region by introducing or producing better varieties than those now grown, especially with regard to drought resistance, yield, quality, earliness, etc.; (2) to conduct such other experiments that might seem advisable for the accomplishment of the greatest possible good to the dry-land interests of the State.

For the purpose of carrying on these investigations it is proposed:

(1) That the Oregon Agricultural Experiment Station, subject to the approval of the governing board, shall provide the necessary land and buildings, team, machinery for planting, cultivating, harvesting, and thrashing, a farm foreman and all ordinary labor, apparatus, and other supplies, and shall make available for use seeds of varieties already under experiment.

(2) The Bureau of Plant Industry shall, subject to the approval of the Secretary of Agriculture, furnish seed of all hybrids and standard varieties now in its possession that are likely to be at all adapted for these experiments and seed of any other new varieties of similar adaptation, and shall provide for one special agent, who shall act as farm superintendent and be in direct charge of all the field plat experimental work at the Station, variety tests, breeding work, etc., the personnel of the special agent to be determined by mutual agreement.

(3) The investigations carried on under this cooperative agreement shall be planned and conducted conjointly by the authorized representatives of the Oregon Agricultural Experiment Station and the Bureau of Plant Industry, and shall be subject to approval of proper authorities in each case.

(4) The seeds of all new varieties of special value developed during these investigations shall be distributed in the localities in which they prove to be of value, the distribution to be made in accordance with such plan as may be jointly agreed to by the Station and Bureau. In the larger plat tests of introduced varieties one-half the amount of grain produced from each variety in excess of the seed required for a second sowing, in all cases where the seed came from the Bureau of Plant Industry, shall be subject to the disposal of the Bureau, the other half to remain the property of the Oregon Agricultural Experiment Station.

(5) At the close of each season's experiments a report in detail of the results of the season's work shall be submitted by the special agent in direct charge of the field work, one copy each to be furnished to the Bureau of Plant Industry and to the Oregon Agricultural Experiment Station. So far as possible thrashed samples of the grain of all varieties under experiment and un-thrashed samples, when particularly desirable, shall accompany the report in each case, such report and samples to be delivered not later than December 31 of that year.

Both parties to the agreement shall be free to use in their official correspondence and in publications the results obtained in these investigations, giving proper credit to the fact that such results were obtained through this cooperative work, and provided that it shall be understood, in case of publications, that the Oregon Agricultural Experiment Station shall give preference to results that are of direct interest to the State of Oregon, and the U.S. Department of Agriculture shall give preference to results that are of interest in connection with similar lines in other parts of the country.

Signed and dated: Director

Oregon Agricultural Experiment Station, and

Chief, Bureau of Plant Industry

LOCATION OF STATION

In accordance with the above, the Superintendent reached Moro July 17, 1909. The act of the Board of Regents, however, definitely locating the station at Moro, did not take place until August 7. It was then necessary for the County Court of Sherman County to regularly vote its appropriation at the next regular meeting, September 7. Unfortunately one member was absent and action was delayed until September 10. At the former meeting, however, proposals on the Committee's first choice of land were called for by the County. The land involved was held by two parties, as follows: That part lying east and south of the Columbia Southern Railway, and owned jointly by E.E. and L. Barnum, was offered for $4,500, about $61 per acre. The adjoining quarter section, owned by the Eastern Oregon Land Company, was offered to the County by their agent, Mr. G.W. Berrian, for $6,400, or $40 an acre. The latter proposition was accepted when the Court met September 10, but as land in this section does not sell above $45 an acre, the offer by the Barnum Bros. was considered exorbitant, and for a time it seemed that new arrangements must be made. A little later, however, this tract was purchased for $3,280, or $44 per acre, making the total cost of land $9,680. An additional $7,500 was appropriated for permanent improvements, initial equipment, etc., thus making the total cash outlay of the County $17,180.

STATION WORK

Everything seemed in readiness for beginning work immediately, and prospects indicated that at least two of the buildings might be enclosed before the October rains set in. It happened, however, that no one present at either of the County meetings was familiar with the agreement between the Committee and the County, and this caused a misunderstanding between the County and the State. In order to avoid the necessity for an extra session of the Court, the judge was empowered, in conjunction with the representative of the Board of Regents, to draw up an agreement satisfactory to both County and State. The superintendent believed that the State expected the County to lease the land to the State, and accordingly the deeds for the land were made out to the County, and the County Court agreed to lease same to the State. A draft to this effect was drawn about October 4, by Judge Hendricks and Professor Scudder, the latter to submit same to the Board of Regents for their approval. The Board of Regents decided that it would be necessary to deed the land to the State. The reluctance of the County officials to comply with this request caused a controversy that lasted until February 17, 1910. At this time the form of the deed was made out, giving the State a title to the land as long as it was used for experiment purposes.

Estimates

While the dispute was going on between the County and State, estimates arrived on October 4 for the following buildings:

1 Superintendent's house
1 Mess house
1 Office, Seed house and Laboratory building
1 Barn.

These were received from G.H. Locey, of Moro, and F.C. Grimes, of Wasco; the former for $7,800, the latter $10,000. Since both estimates were above the amount available, it was necessary to reject them and revise the plans. Separate bids on lumber and building material, carpenter work, plastering and plumbing were next called for. The incidental work, such as foundations, wiring and tinning, was to be done by day labor under the supervision of the superintendent.

A number of lumber concerns throughout the State were asked for estimates. The lowest and most satisfactory in every way was that of the McMinnville Lumber Company, McMinnville, Ore., for $2,290.00. This bid, received about November 1, 1909, included lumber, cement, sash and doors for the four buildings, but could not be accepted as County Warrants, in which the county appropriation had been issued, could not be converted into cash at the time. One factor affecting the immediate sale of the warrants was the delay between the County and State in arranging the transfer of the station land. They were finally disposed of March 14, 1910.

Spring Work

As the entire station had been cropped the previous year, plowing was at once begun in an attempt to get some of the land ready for spring seeding, and this was used for the experimental work later described. Plowing was continued during the spring until the entire station was turned.

In view of the fact that spring work had been delayed so long, it seemed advisable to thoroughly establish the experimental work before beginning building operations. This could not be done, however, as the law (above quoted) provided that the land, buildings, and permanent improvements be turned over without cost to the State before their appropriation could be used, and part of this money had to be drawn to complete the spring experimental work. It was therefore necessary to begin the buildings at once.

Completion of Buildings

A resubmission of estimates now showed that the price of lumber had risen so much that the bill for the three buildings absolutely necessary was $2,250, whereas the previous fall it was $2,290 for all four, consequently the mess house was eliminated, and the superintendent's house, the office, laboratory and seed house, and barn were completed during the summer of 1910.

Results of Experiments

While the building operations interfered greatly with experimental work, some results were obtained that will be valuable not so much for what they indicate in yields as for the purpose of showing in what direction to avoid useless work in the future. The results obtained were with variety tests of spring wheat, oats, barley, corn and millets. Some grass plats were also started. Meteorological instruments were installed and observations taken during part of the season. Best of all, the entire station soil was gotten into better tilth by deep plowing and much was summer fallowed, thus eradicating many of the weeds which infested the station. Forty acres were seeded to Bluestem spring wheat, which produced about 320 bushels of grain of fair quality which will be largely used for seed during the spring of 1911.

FINANCIAL STATEMENT

Amount expended by Government to December 31, 1910	$ 3,696.97	
Amount expended by State to December 31, 1910	5,311.56	
Amount expended by County to December 31, 1911		7,430.47
		$16,429.00
Due D. Stanton	10.50	
Due Moro Hdwre. & Imp. Co.	.20	
Total		$16,449.95

The purposes for which the above money was expended are as follows:

Buildings	$ 5,921.05
Expenses and incidentals	645.90
Fence	46.97
Office furniture and equipment	317.20
Labor	734.95
Clerical help	41.75
Insurance and legal fees	185.38
Plowing	71.25
Seed	112.20
Supervision	3,487.50
Tools and apparatus	1,514.24
Teams	1,734.84
Travel	599.85
Well	1,026.89
Orren Beaty, foreman (advanced for current expenses)	8.78
Cash on hand	1.15
	$16,449.95

SOIL AND CLIMATIC CONDITIONS PECULIAR TO STATION SITE

The station is representative of a section including all Sherman, Gilliam and Morrow Counties; the eastern half of Wasco, the northeast part of Crook, and the north-western part of Wheeler Counties. The entire area is underlaid with a basaltic rock, known as Columbia Basalt, and is the result of repeated overflows of lava. Previous to the last flow, a large lake, known as John Day Lake, covered practically the entire section and interposed a layer of sedimentary deposit. The soil is therefore both sedimentary and residual, and upon the latter, or higher, areas, practically all the farming of the entire area is done. The folding and elevation of the entire formation of Columbia Basalt has given the whole country its present topography of vast, very rolling, treeless hills. Professor Scudder estimates that in this area there are approximately three million acres, of which fully two million are tillable, and of the latter 1,500,000 may be dry farmed.

In texture, the soil is a dark brown silt loam, comparing very closely, if not wholly, with the type classified by the Bureau of Soils of this Department as Yakima silt loam. The surface soil is somewhat darker than that of the subsoil on account of the organic matter it contains. It might be explained here that the Columbia Basalt, according to the U.S. Geological Survey, generally contains from 46% - 57% of silica, and 11% - 22% alumina, together with lime, magnesia and potash, in proportions varying from a small fraction of 1% to over 10%. It is the presence of lime, potash and phosphoric acid in the basalt that gives the resulting soil its richness.

Through the area the soil varies from a sandy silt loam in that section lying nearest the Columbia to a richer silt loam in the southern part. Its depth is from a few feet to nine feet, and is said to be deeper in Sherman County than in Gilliam and Morrow.

ALTITUDE

The elevation of the narrow belt along the Columbia, where practically no grain-farming is done, is from one to two hundred feet. Most of the wheat farming begins on the adjacent uplands at 500 to 1,000 feet elevation, and is continued toward the south where the elevation reaches, at some points, 3,000 feet.

PRECIPITATION

The annual precipitation varies from north to south. At points along the Columbia River it is 8 to 9 inches, increasing to 15 inches in the southern end of the area.

DESCRIPTION OF SITE

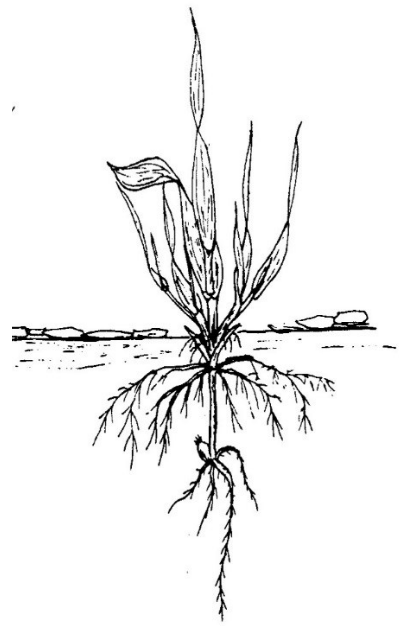
The site selected for the farm lies just north and east of the town of Moro and is bounded on the west by the Columbia Southern Railway and partly on the south by the main wagon road east from Moro. The Columbia Southern station is in the eastern part of the town at a short distance from the station buildings which are located practically at the intersection of the Railroad and wagon road. It will be seen from the accompanying contour map that the elevation of the station buildings is 1,845 feet, and that there is a difference in height of 175 feet between the lowest point along the railroad and the highest point well toward the eastern end. Practically every direction of slope is present. The slopes also vary on the plats from a rise of 11 feet per 100 to practically level land. In spite of the wide variation of slope, however, the limited rainfall causes the whole section to be ordinarily uniform, except where the underlying rock strata approach the surface in what are known as "scab" or waste lands. The station soil is typical of the entire area, and varies in depth from 3 to 9 feet.

WEATHER DATA

The record in the following table, compiled from the annual reports of the Weather Bureau, is somewhat broken and is not exactly representative of the station conditions, as it was taken at a point eleven miles south of Moro.

The precipitation is figured from the average monthly, and thus the mean annual is obtained. It is interesting to note that of the 10.4 in mean annual, 5.61 fell in October, November, December and January, and that during the growing season, March, April, May and June, only 3.4 inches are received. The general weather conditions will not be discussed further at this time, for the above data seem too meagre to be reliable. It is, however, desirable to call attention to the above averages to show the importance of tillage that will conserve winter precipitation until the time when it is required by the growing crop.

Humidity is a very important factor in crop production in this section. It is a matter of common observation that the west winds, blowing from the Pacific Ocean over mountains not high enough to rob them of all their moisture, do much to sustain crops; but east winds whose humidity has been lowered by the Rocky Mountains, cause disastrous results.



Appendix 10 – Pendleton Station's First Annual Report (1930)

REPORT OF THE PENDLETON FIELD STATION
PENDLETON, OREGON 1929-1930

D.E. Stephens, Senior Agronomist, and
G.A. Mitchell, Assistant Agronomist

Table of Contents

(***The first 15 pages of the 1929-1930 report were reproduced to provide longevity for these documents***)

REPORT OF THE PENDLETON FIELD STATION: 1929, 1930

INTRODUCTION

In northeastern Oregon and southeastern Washington, immediately west of the Blue Mountains, are large tracts of productive land that have been devoted to grain growing for nearly a half century. These were the first lands to come under the plow east of the Cascades in either state. At first continuously cropped, then later alternately cropped to grain and left fallow, these fertile lands still produce yields of wheat of from 35 to 45 bushels or more per acre. Corn and leguminous crops such as peas, beans and alfalfa, have been grown by many farmers but no successful or profitable crop rotation system has been introduced or established in any locality in this area.

The farmers of this section, most of whom are large operators, have been generally prosperous. As a class, they rank high in intelligence and progressiveness. They always have willingly cooperated with the Extension Service and Experiment Station in trying out new crops or cropping methods.

As a result of cooperative fertilizer demonstrations by farmers and the County Agricultural Agent of Umatilla County and the interest aroused in improved grain varieties by the cooperative cereal-testing nursery in that County, farmers of Umatilla County, in conjunction with civic organizations in the City of Pendleton, made an organized attempt in 1924 and 1925 to secure funds from the Oregon State Legislature for the establishment of a branch station in Umatilla County to study crop rotation, fertilizer, and crop improvement problems.

LEGISLATIVE ENACTMENT

Through the efforts of State Senator Roy W. Ritner and other members of the Umatilla County delegation a bill appropriating $2000 annually for crop rotation and fertilizer trials in Umatilla County and cereal nursery experiments in Eastern Oregon, passed both houses of the Oregon Legislature in 1925. This bill was vetoed by Governor Pierce. During the session of 1927 a similar bill was again passed by the Legislature and signed by Governor Patterson. This latter bill, like the first one, was sponsored by the Umatilla County delegation in the Legislature and Mr. Ritner, although not a member of the Legislature rendered valuable aid in securing favorable action by the Legislature and the approval of the Governor. Following is a text of the bill passed by the Oregon Legislature:

GENERAL LAWS OF OREGON, 1927, CHAP. 402, Page 561
AN ACT (H. B. 590)

Authorizing grain and forage crop experimental and demonstration work within counties east of the Cascade mountains, and for crop rotation experimental work with Umatilla County, and providing an annual appropriation, and declaring an emergency.

Be It Enacted by the People of the State of Oregon:

Section 1. The director of the Oregon Experiment Stations is hereby authorized to conduct experimental and demonstration work in counties east of the Cascade Mountains for the purpose of testing and demonstrating more profitable wheat varieties, more profitable crops on lands now producing wheat, and suitable grasses for grazing lands. Such work shall be conducted through grain and forage crop nurseries and by such means as he may deem proper.

Section 2. The director of the Oregon experiment stations is hereby authorized to conduct in Umatilla county crop rotation experimental and demonstration work for the purpose of establishing a profitable cropping system that will reduce the summer fallow acreage, decrease the present size of the farm unit necessary to make a living and stabilize land values.

Section 3. The work provided for in this act shall be conducted only in counties having agricultural agents or other local agencies, who may be deemed qualified by the director of the Oregon experiment stations to cooperate in conducting the work.

Section 4. No money appropriated under this act shall be expended for purchase or rental of land, but the county desiring the experimental or demonstration work shall provide such land as may be necessary.

Section 5. For the purpose of carrying out the provisions of this act there is hereby appropriated annually out of the money in the general fund in the treasury of the state of Oregon, not otherwise appropriated, the sum of two thousand dollars ($2,000), or so much thereof as may be necessary.

Section 6. It is hereby adjudged and declared that existing conditions are such that this act is necessary for the immediate preservation of public peace, health and safety; and, owing to the urgent necessity of putting into effect the provisions of this act before the time of acting in 1927 is past, an emergency is hereby declared to exist, and this act shall take effect and be in full force and effect from and after its approval by the governor.

Approved by the governor March 3, 1927.

Filed in the office of the secretary of state March 3, 1927.

ACQUIRING LAND AND FEDERAL AID

Inasmuch as the bill passed by the legislature specified that no part of the fund should be expended for the purchase of land, the members of the county court of Umatilla County ---- Messrs. Schannep, Bean and Hales --- were appealed to and a tract of 40 acres of land near Adams was purchased from Mr. L. L. Rogers. In the meantime the Farm Bureau and Pendleton civic organizations succeeded in interesting Senators Steiwer and McNary in a plan to secure Federal help for the establishment of an adequately equipped crop rotation station in Umatilla County. Through the efforts of these mean a sum of $10,000 was added to the annual appropriation of the Office of Dry Land Agriculture of the U. S. Department of Agriculture for crop rotation, tillage and fertilizer experiments in Umatilla County, Oregon.

With the additional Federal funds more land was needed. None could be secured adjoining the tract already purchased by the county. Mr. Rogers generously agreed to take back the land purchased from him and, after considerable investigation of available sites, another tract of 160 acres located between Adams and Pendleton, was purchased by the county, through the county court, at a cost of $30,000 or $187.50 per acre and leased to the State for conducting experimental work.

The site acquired is located about 2 miles east of Havana, a railway station on the O.W.R. & N. about 10 miles from Pendleton and 5 from Adams. The topography of the land is fairly level. The soil seems quite uniform and typical of large areas in this section. In productiveness, the station farm is probably representative of the average good wheat land in eastern Umatilla County. Complete chemical and mechanical analyses of the soil are not yet available. These and a further detailed description of the station farm will be included in a later report.

Following is a copy of the lease executed by the County Court of Umatilla County to the Oregon State Agricultural College:

UMATILLA COUNTY
TO
THE STATE AGRICULTURAL COLLEGE
OF THE STATE OF OREGON

WHEREAS, by an Act of the Legislative Assembly of the State of Oregon, Chapter 402 Laws of Oregon, 1927, passed by the Legislature of 1927, provision was made for the Oregon Agricultural Experiment Station to conduct crop rotation experimental and demonstration work in Umatilla County, Oregon, contingent upon the people of said Umatilla County, through their County Court or otherwise, to provide, without cost to the State, suitable land for such experimental and demonstration work, and

WHEREAS, the people of Umatilla County, through their County Court, in consideration of the location of said experimental and demonstration work in Umatilla County, of the State appropriation, and of Federal cooperation in establishing and maintaining said experimental work, and for the purpose of rendering most effective such investigations for the benefit of Umatilla County, has agreed to lease to the State Agricultural College of the State of Oregon, for use by the Agricultural Experiment Station in accordance with the provisions of said Act the hereinafter described lands.

Said County Court of Umatilla County does hereby grant, lease, and let to the said State Agricultural College of the State of Oregon for use by the Agricultural Experiment Station the following described lands, to wit:

The southeast quarter of Section Twenty-four (24) in Township Three (3) North of Range Thirty-three (33) East of the Willamette Meridian, in Umatilla county, Oregon, which said tract of land is otherwise described as Lots 11, 12, 17 and 18 of said Section, Township and Range.

For and during such time hereafter as the said premises above described shall be maintained and used as a branch Agricultural Experiment Station of the State Agricultural College of the State of Oregon.

TO HAVE AND TO HOLD the above described and demised premises to the said State for so long hereafter as the same shall to be used for the purposes above mentioned. And for such time hereafter as the above described premises are used and maintained as a branch Agricultural Experiment Station of the State Agricultural College, the said State shall at all times peaceably and quietly have, hold, and enjoy said premises without any trouble or hindrance of or from the said County or any person or persons claiming by, through, or under them.

PROVIDED, however, that it is expressly understood and agreed between the parties hereto, that this Lease is made upon condition that it shall be subject to such change as may be agreed upon by the parties hereto in order to provide for cooperation with the United States Department of Agriculture and thereby secure the expenditure of Federal appropriations available, or which may become available, to best advantage of said experimental and demonstration work.

This lease is made upon the condition that if at any time hereafter the said Agricultural College should abandon said premises or the said premises should cease to be used as a branch Agricultural Experiment Station of said College then such abandonment or non-use shall operate to terminate this lease.

IN WITNESS HEREOF the parties hereto have hereunto set their hands and seals this 8th day of September, 1928.

Signed by members of County Court of Umatilla County, the President and Secretary of the Board of Regents of the Oregon State Agricultural College, and the Director of the Oregon Agricultural Experiment Station.

MEMORANDUM OF UNDERSTANDING BETWEEN
THE OREGON STATION AND BUREAU OF PLANT INDUSTRY

The working agreement or memorandum of understanding between the Oregon Agricultural Experiment Station and the Bureau of Plant Industry was signed by the Director of the Oregon Station and the Chief of the Bureau of Plant Industry on November 22, 1928. Following is a copy of this agreement.

MEMORANDUM OF UNDERSTANDING
Between
THE OREGON AGRICULTURAL EXPERIMENT STATION
and
THE BUREAU OF PLANT INDUSTRY, U. S. DEPARTMENT OF AGRICULTURE

Effective December 1, 1928.

The purpose of this cooperative memorandum is to establish and maintain a Dry Land Field Station to be known as the Pendleton Field Station for the conduct of cooperative research work bearing on the production of field crops, including wheat, barley, oats, corn, etc., through breeding, tillage, rotation, and other experimental methods; and for cooperative investigations at other field locations in eastern Oregon.

A. The Oregon Agricultural Experiment Station agrees:

1. To furnish approximately 160 acres of land for the establishment of a station and to erect necessary farm buildings.
2. To make necessary repairs on the buildings and other improvements normally construed as pertaining to ownership of the land.
3. To contribute toward the salary of the superintendent.
4. To make available land and facilitate at other points in eastern Oregon as may be practicable.
5. To make such other contributions to cooperative work as may be found practicable from time to time.

B. The Bureau of Plant Industry agrees to contribute:

1. To the salary of a station superintendent.
2. For the maintenance of a technical staff consisting of one or more investigators who will supervise the crop investigations under the supervision and direction of the superintendent.
3. For necessary equipment other than land and buildings, for the establishment of a field station near Pendleton, Oregon, and its future maintenance.
4. For necessary labor and supplies for the cooperative field work of the stations.
5. For necessary travel expenses.

C. It is mutually agreed:

1. That the experimental work on the station will be planned and conducted jointly by duly authorized representatives of the Oregon Agricultural Experiment Station and the Bureau of Plant Industry, and shall be subject to the approval of the proper authorities in each case.
2. That the superintendent and other members of the technical staff assigned to the station shall be acceptable to both agencies.
3. That both parties to this agreement shall be free to use in official correspondence or in publications any of the results obtained in these investigations, giving due credit to the cooperating agency. Publication may be joint when desirable.
4. That the obligations of the Bureau of Plant Industry and those of the Oregon Agricultural Experiment Station, are contingent respectively upon appropriations being made by Congress and by the Oregon Legislature from which the expenditures may legally be met.
5. Property purchased from Federal funds shall remain the property of the United States Department of Agriculture, and subject to the removal or other disposition upon the termination of this agreement; property purchased from State funds shall likewise remain the property of the Oregon Agricultural Experiment Station and subject to its disposition.
6. Surplus crops produced in connection with this cooperative work and not needed in the maintenance of the station or for experimental purposes, shall be the property of the Oregon Agricultural Experiment Station; such reports of sale of produce as may be mutually agreed upon shall be made to the Bureau of Plant Industry.
7. For the fiscal year ending June 30, 1929, expenditures under this cooperative memorandum will be approximately as noted below:
   Oregon Agricultural Experiment Station … $6,000 to $7,000
   Bureau of Plant Industry …………………. $9,000
8. Thereafter, in advance of each fiscal year a budget for this work will be arranged by correspondence and made a part of this agreement.
9. This agreement may be terminated at the end of a calendar year by either party upon six months notice.

Date November 22, 1928 (Signed) James T. Jardine
Director, Oregon Agricultural Experiment Station

Date November 28, 1928 (Signed) W. A. Taylor
Chief, Bureau of Plant Industry

FINANCIAL

The cost of the buildings and permanent improvements, paid for from the sales and State funds, has been $12,583.71. These include the implement shed, the Superintendent's residence, the well, and telephone lines.

Permanent equipment purchased by the Office of Dry Land Agriculture has been $8,096.80.

Two additional buildings, one suitable for office and laboratory use and one for seed storage, are urgently needed. One of these should be constructed in 1931 if possible.

Figs. 1, 2, and 3 are photographs of the residence (rear and front views) and the implement shed.

Following is an itemized list of the cost of the buildings and improvements made on the station to date.

House contract	$6,069.80	
Extras: hardware, extra wiring, phone niche, etc.	127.50	
House equipment, blinds, linoleum, light fixtures	152.14	
Electric stove and water heater	290.00	
Hot water heating system	1,234.00	
Architects fee	365.00	
Fireplace fixtures	25.20	$8,263.64
Shrubbery and trees	232.90	
Grass seed	89.56	271.90
Implement shed 24' x 80'	1,213.25	1,213.25
Septic tank, two compartments each 5'x5'x5'	150.00	
Tile for sewage system	89.56	239.56
Well 283 feet deep, $4,50 a foot for drilling	1,273.50	
Well house, 8' deep, 10' wide and 14' long with concrete walls and wooden roof	150.00	
2 h.p. electric motor with starting and pressure switch	76.50	
3 h.p. gasoline engine	85.58	
1000 gallon pressure tank	201.90	
Myers 660Am working head	130.80	
Pump rods, check valves and gauges	94.75	
Cylinder 2 ¾" x 45" long	20.00	
122 feet of 3" plugged and reamed pipe	79.51	
Pipe and fixtures in water distribution system	211.59	2,327.11
Telephone line wire and poles (2 ¼ miles)	168.25	
Cost of rebuilding lne 39F4 (our portion of total cost)	100.00	268.25
Total		$12,583.71

Following is an itemized list of itemized expenditures for permanent equipment made by the Office of Dry Land Agriculture for the Pendleton Field Station up to March 15, 1931.

	Cost	
1. Office equipment		
1 Desk	$ 30.00	
1 Typewriter	75.00	
1 Filing cabinet & 3 chairs	94.11	
1 Dalton adding machine	98.79	
1 Monroe calculator	297.50	
1 Heater	25.00	
1 Telephone set	25.84	
1 Camera	125.00	
Miscellaneous	6.75	777.99
2. Automobiles & Trucks		
1 Ford Model A pick-up	531.00	531.00
3. Livestock		
2 Horses	420.00	420.00
4. Farm Machinery and Equipment		
1 Drill, grain (Van Brunt 16-6 single disk)	132.69	
1 Drill, grain (combination grain & fertilizer) McCormick 11-7	163.87	
1 Drill, electric (1/2-inch)	48.00	
1 Drill, (Planet Jr. Hand Seeder)	13.84	
1 Harrow – 4 section spike tooth	44.75	
1 Harrow – spring tooth, 4 section	46.31	
1 Harrow – McCormick one-way disk	237.50	
1 Harrow cart	18.50	
1 Harrow hitch	4.50	
1 Harrow, 16-foot disk	128.15	
1 Plow – John Deere 2-way tractor	191.50	
1 Plow – John Deere 2-way sulkey	117.50	
1 Plow – Syracuse fence	18.50	
6 Plow jointers	35.97	
1 Weeder – McCormick-Dearing Rod	112.00	
1 Grain binder (McCormick 6-foot)	216.40	1529.98
1 Combine harvester (Gleaner)	1016.50	
cost of remodeling	438.85	1455.35
1 Model T Ford engine	271.05	
1 Air Cleaner (Ellis)	12.00	
1 Tractor (Caterpillar, Holt 15)	1697.00	
1 Mower (5-foot John Deere)	92.50	
1 Hay rake (10-foot McCormick)	53.25	
1 Corn planter (John Deere 2-row)	75.00	
2 Hay rakes	99.60	
1 Wagon (steel wheels)	66.97	
1 set Harness	78.79	
3 Horse collars	23.50	
1 Anvil	24.60	
1 Forge	19.00	
1 Gasoline pump and hose	26.20	

1 Scale, platform (Fairbanks Morse)	37.96	
1 Cultivator (one-horse)	13.27	
2 Belts	36.90	
1 Zerk grease gun	14.00	
1 Grease pump	12.50	
1 Tool grinder	12.50	
1 Grindstone	10.25	
1 Treating machine (Culkins)	33.00	
1 Fanning mill (Clipper)	43.05	
1 Barrel churn	14.00	
1 Pipe stock and dies	11.00	
1 Set soil tubes	90.00	
1 Surveyors chain	20.00	
Miscellaneous farm tools and equipment	280.34	3168.23
5. Weather Instruments		
1 Evaporation tank	36.25	
2 Thermometers and supports	14.00	
2 Rain and snow gauges	14.00	
1 Anemometer	70.00	
1 Instrument shelter	80.00	214.25
Total		$8,096.80

Photographs:
1. Superintendent's Residence, Pendleton Field Station, Aug. 1930 (rear)
2. Superintendent's Residence, Pendleton Field Station, Aug. 1930 (front)

Appendix 11 – Two Amendments to Land Leases at the Pendleton Station

1948 – The 7th paragraph was newly inserted into the 1928 lease agreement, and the then-current signatories differed from the original lease.
1966 – A block of land was transferred from Umatilla County to the U. S. Department of Agriculture, to establish the Columbia Plateau Conservation Research Center.

UMATILLA COUNTY
TO
THE STATE AGRICULTURAL COLLEGE
OF THE STATE OF OREGON

WHEREAS, by an Act of the Legislative Assembly of the State of Oregon, Chapter 402 Laws of Oregon, 1927, passed by the Legislature of 1927, provision was made for the Oregon Agricultural Experiment Station to conduct crop rotation experimental and demonstration work in Umatilla County, Oregon, contingent upon the people of said Umatilla County, through their County Court or otherwise, to provide, without cost to the State, suitable land for such experimental and demonstration work, and

WHEREAS, the people of Umatilla County, through their County Court, in consideration of the location of said experimental and demonstration work in Umatilla County, of the State appropriation, and of Federal cooperation in establishing and maintaining said experimental work, and for the purpose of rendering most effective such investigations for the benefit of Umatilla County, has agreed to lease to the State Agricultural College of the State of Oregon, for use by the Agricultural Experiment Station in accordance with the provisions of said Act the hereinafter described lands.

Said County Court of Umatilla County does hereby grant, lease, and let to the said State Agricultural College of the State of Oregon for use by the Agricultural Experiment Station the following described lands, to wit:

The southeast quarter of Section Twenty-four (24) in Township Three (3) North of Range Thirty-three (33) East of the Willamette Meridian, in Umatilla county, Oregon, which said tract of land is otherwise described as Lots 11, 12, 17 and 18 of said Section, Township and Range.

For and during such time hereafter as the said premises above described shall be maintained and used as a branch Agricultural Experiment Station of the State Agricultural College of the State of Oregon.

TO HAVE AND TO HOLD the above described and demised premises to the said State for so long hereafter as the same shall to be used for the purposes above mentioned. And for such time hereafter as the above described premises are used and maintained as a branch Agricultural Experiment Station of the State Agricultural College, the said State shall at all times peaceably and quietly have, hold, and enjoy said premises without any trouble or hindrance of or from the said County or any person or persons claiming by, through, or under them.

It is further understood, stipulated, and agreed by and between the parties hereto that the County Court of Umatilla county does hereby give and grant unto the State of Oregon, acting through and by the Board of Higher Education of the State of Oregon, the right to remove at any time any building or buildings constructed on the heretofore described land with funds under the control of the State of Oregon.

PROVIDED, however, that it is expressly understood and agreed between the parties hereto, that this Lease is made upon condition that it shall be subject to such change as may be agreed upon by the parties hereto in order to provide for cooperation with the United States Department of Agriculture and thereby secure the expenditure of Federal appropriations available, or which may become available, to best advantage of said experimental and demonstration work.

This lease is made upon the condition that if at any time hereafter the said Agricultural College should abandon said premises or the said premises should cease to be used as a branch Agricultural Experiment Station of said College then such abandonment or non-use shall operate to terminate this lease.

IN WITNESS HEREOF the parties hereto have hereunto set their hands and seals this 8th day of September, 1928.

County Court of Umatilla County, Oregon

In the presence of:	James H. Sturgis (County Judge)
Mrs. E. B. Casteel	Wm. R. Meiners (Commissioner)
Jessie M. Bell	Henry L. Biamont (Commissioner)

State of Oregon, Acting through and
By the Board of Higher Education of the State of Oregon
Charles D. Byrd (Secretary)
?????? (Comptroller)
Recommended by:
R. S. Besse (acting)
Director of the Agricultural Experiment Station

This lease amends original drawn September 8, 1928.

BARGAIN AND SALE DEED (288839)
Book 285, Page 712

Umatilla County, a political subdivision of the State of Oregon conveys to the United States of America all that real property situated in Umatilla County, State of Oregon, described as:

A parcel of land lying in the Lots 17 and 18 otherwise designated as S ½ of the SE ¼ of Sec. 24, T3N, R 33, EWM, Umatilla County Oregon, and being a portion of that property conveyed by that deed to Umatilla County recorded in Book 135, page 371, of Umatilla County Records of Deeds. The said parcel being that portion of said Lots 17 and 18 which is lying in the SE corner of the said Sec. 24, T3N, R33, EWM, to-wit:

The South 499 feet and westerly 1300 feet parallel to (and 499 feet when measured at right angles to) the South line and from the said Southeast corner of the said Section 24.

The parcel of land to which this (469’ × 1300’ more particularly described) description applies contains 14.00 acres and a 30 foot strip lies within the said Lots 17 and 18 as existing right of way, title to which hereby is acknowledged to in the public, so long as said property is used for a United States Regional Soil and Water Conservation Research Facility of the Agricultural Research Service of the United States Department of Agriculture. When said property is no longer so used, the interest of the grantee, its heirs or assigns shall automatically terminate.

Dated this 26th day of July, 1966.

D. R. Cook	Cecil B. Stanton	Walter A. Holt
County Judge	County Commissioner	County Commissioner

STATE OF OREGON, County of Umatilla
July 26, 1966

Personally appeared the above-named D. R. Cook, County Judge, Walter A. Holt, County Commissioner, and Cecil Stanton, County Commissioner, and acknowledged the foregoing instrument to be a voluntary act. Before me: Jessie M. Bell
Umatilla County Clerk
Filed for record Aug. 29, 1966 at 11:50 A.M.
Jack Folsom, Recorder of Conveyances

This is a comprehensive yet abbreviated history of rural branch experiment stations that serve Oregon's semi-arid, rainfed wheat industry. They are the Pendleton and Sherman Stations of the Columbia Basin Agricultural Research Center, and the USDA-ARS Columbia Plateau Conservation Research Center, co-located with the Pendleton Station. Scientists at these locations have been addressing the needs of dryland agriculture in the Inland Pacific Northwest for more than a century.

The Sherman Station, at Moro, was established in 1909 and the Pendleton Station, near Pendleton, was established in 1928. They were founded by the Oregon Agricultural Experiment Station and the United Stated Department of Agriculture - Bureau of Plant Industry. Their purpose is to conduct research that supports the livelihoods of farmers practicing dryland agriculture, which is defined in the preface. The stations were merged administratively for a decade during the 1930s and, since 1970, were merged again as the Columbia Basin Agricultural Research Center. Both founding agencies have maintained a continuous presence at both stations. In 1970, U.S.D.A. unit at Pendleton was re-organized as the Columbia Plateau Conservation Research Center.

The book includes a history of both regions before the stations were established, processes and facilities developed while establishing each station or research center, climates of the region, descriptions of long-term experiments both on- and off-station, and summaries of research on tillage systems, crop rotations, alternate crops, weeds, plant pathology, insect pests, soil chemistry, soil water, and plant growth and development. Also described are facets of extension education, research funding, and staff contributions to society and nearby communities. Appendices provide lists of administrators, scientists, extensionists, technical publications (895, from 1909 to 2019), and annual reports. Replications of important early documents are included; the first annual reports from the Sherman Station (1910) and the Pendleton Station (1930), and the original land deeds and their amendments.

This book describes experimental successes and failures for agricultural research in a semiarid region of the northwestern USA.