Special Report 1074
June 2007

2007 Dryland Agricultural Research Annual Report

Oregon State University | Agricultural Experiment Station

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Oregon State University

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Cooperating Research Units

Columbia Plateau Conservation Research Center
USDA-Agricultural Research Service

Columbia Basin Agicultural Research Center
Oregon State University

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CONTENTS

Introduction

Staffs of the Columbia Basin Agricultural Research Center (CBARC, Oregon State University [OSU], Pendleton and Sherman Stations) and the Columbia Plateau Conservation Research Center (CPCRC, USDA-Agricultural Research Service [ARS], Pendleton) are pleased to present some of their research results. This Special Report contains a representative sample of the work in progress at these centers. A collection of Special Reports over a three-year period will give a more complete assessment of the productivity and applicability of research and education. Special Reports from previous years can be found on the CBARC website http://cbarc.aes.oregonstate.edu. Past issues are available through the extension office and USDA. ARS website http://www.pwa.ars.usda.gov/pendleton/cpcrc/index.htm. Changes in staffing, programming, and facilities at these centers during the past year are summarized below.

Promotions and Awards

Within ARS, Patricia Frank received a promotion in 2006. Performance awards were awarded to Darren Van Cleave, Alan Wernsing, Rich Greenwalt, Stewart Wuest, Mark Siemens, Yi Liang, Patricia Frank, Dave Robertson, and Judy Skjelstad for outstanding performance.

Staff Changes

ARS:

Dr. Yi Liang, postdoctoral fellow at ARS, left to accept a faculty position at University of Arkansas. Linda Baugh, Location Administration Officer retired, Don Hullick, Engineering Technician, left employment with ARS to take a faculty position at Walla Walla College. Temporary or term employees new to ARS since the last report were Christopher Iacoboni, Physical Science Technician; Felicity Dye, Biological Science Technician; Patrick Scharf, Engineering Technician; and a student employee, Cara R Wendel. Summer student employees for 2006 included: Roxie Cannon, Darren Van Cleve, Byron Morris, Wes Matlock, and Mandy Wuest. Byron Morris was hired through the student summer internship program administered by the Confederated Tribes of the Umatilla Indian Reservation. Darren Van Cleve was sponsored with funds from the Pacific West Area Office Student Internship Program. Jan Eitel, Ph.D. graduate student with College of Natural Resources University of Idaho, continued his remote sensing research project with Dan Long who serves as co-chair of his thesis committee.

CBARC:

There were a number of staff changes at CBARC in 2006. Christy Watson left the Plant Pathology program to accept a position in Spokane. Dr. Guiping Yan was hired as a Research Associate and Alison Thompson was hired as a Faculty Research Assistant. Nathan Blake resigned from the Club Wheat Breeding and Statewide Variety Testing program to accept a position with a seed company in central Washington. Sandy Frost resigned from the Weed Science program to become a County Agricultural Agent in Wyoming.

OSU summer student employees for 2006 included Rebecca Franke, Tyler Greenwalt, Matt Gundlach, Haley Hams, Debi Hyatt, Loren James, Audrey Marier, Emily Matlock, Nolan Mills, Chelsea Pankratz, Kent Pankratz, Alixanne Pinkerton, Andrew Pinkerton, Ashley Spratling, Roger Straughan, Talia Vogler, Andy Wellington and Paul Wilkerson. The summer workers provide invaluable assistance to the research programs and they make a significant contribution to the overall success of the research station.

Catherine Tarasoff, from British Columbia, Canada completed a Ph.D. program in fall of 2006 with co-advisors Dan Ball and Carol Mallory-Smith from CBARC and the Department of Crop and Soil Sciences, respectively. The title of Dr. Tarasoff's dissertation is "The biology and ecology of weeping alkaligrass and Nuttall's alkaligrass. These grasses are weeds in grass seed production fields in eastern Oregon and Washington.

New Projects and Grants Received

OSU scientists received more than $511,000 in grants and contracts in 2006; the three year average (2004 – 2006) is $576,000. Grant sources include regional competitive grant programs such as STEEP III, and the Grass Seed Cropping Systems for a Sustainable Agriculture; commodity commissions such as the Oregon Wheat Commission and the Washington Turfgrass Seed Commission and private industry. The plant pathology program expanded its focus on 1) molecular methods to detect and identify fungi and nematodes in plants and soil, 2) use of molecular markers to identify plants carrying genes for resistance to these root pathogens, 3) identifying levels of resistance to lesion nematodes in PNW wheat and barley varieties, and 4) improvement of genetic resistance against selected root diseases in PNW wheat varieties.

ARS scientists received more than $400,000 in grants and contracts in 2006. An interagency agreement was established with USDA Natural Resource Conservation Service to enhance USDA-NRCS conservation programs through USDA-ARS research and technical assistance. Under this agreement, ARS will investigate seeding winter wheat on precise contours to prevent water erosion in conventional summer fallow fields, compile existing data to support designation of Wildhorse Creek as a Special Emphasis watershed, develop a new, reaper/flail-based harvesting system that will harvest the crop and size crop residue for optimal no-till drill performance in heavy residue, predict carbon storage under varying tillage or amendment application scenarios, and recommend management strategies to improve soil carbon content, and identify management practices that contribute to the formation of recalcitrant carbon pools from wheat residue. Further, a cooperative agreement was established with John Deere Agri Services to investigate practical uses of multispectral aerial imagery in precision crop management. In 2006, the appropriated research project entitled: Soil conservation systems for sustainability of PNW agriculture, was renewed for another five year implementation (2007-12). This research project will be undertaken jointly with the ARS Land Management and Water Conservation Research Unit at Pullman, WA.

Stewart Wuest and Dan Long initiated a research project to investigate the use of tractor guidance systems for preventing accumulation and concentration of runoff from broad hilltops which sometimes causes erosion on adjacent slopes. The research is targeted toward deep-furrow planting systems, and is supported by an NRCS grant. The computer software development is being done by Mike Bailey and graduate student Randall Rauwendaal of OSU.

Facilities and Equipment

OSU:

- Installed new septic system including septic tank and leach field and decommissioned old system using Building Use Credit funds from the College of Agricultural Sciences.
- Prepared greenhouse for major renovation which will take place in 2007.
- Completed liquid fertilizer handling system.
- Fabricated Weedseeker plot sprayer with datalogger.
- Received a five ft shear from surplus.
- Upgraded molecular diagnostic equipment in the plant pathology laboratory.
- Upgraded the plant growth room in the OSU headhouse (potting shed).

ARS:

- Completed upgrade of heating, ventilation, and air conditioning system.
- Purchased with soft funds a small plot seeder with two belt cones for applying seed and fertilizer.
- Purchased solid set, sprinkler irrigation system with soft funds.
- Acquired all-wheel drive Kubota utility vehicle with soft funds.
- With soft funds, acquired an AutoFarm GPS-based autosteer system for both Challenger 50 and John Deere 2355 tractors

Training

All OSU and ARS employees licensed to apply pesticides completed the appropriate recertification training. Safety training on specific topics was a regular part of the monthly OSU staff meeting. Many ARS and OSU employees participated in first aid, cardio-pulmonary resuscitation (CPR) and automatic external defibrillator (AED) training

John Williams attended Soil and Water Conservation Annual Conference presenting a paper and poster, and attended a workshop on Cold Regions Soil Erosion. Chris Roager attended Hazardous Waste and Pre-Retirement Planning; Amy Baker completed Introduction to ArcGIS I and II, Managing the Training Program, Conducting Classroom Safety, Developing Training Courses, Conducting OJT Training and Basic Statistics; Patricia Frank attended Qualifications Analysis Workshop; Steve Albrecht attended the Pre-Retirement Planning; Donald Hulick attended the Pre-Retirement Planning; Katherine Skirvin attended the Pre-Retirement Planning; Linda Baugh attended Contracting Officer's Representative Course;

Outreach

OSU scientists and Extension Specialists made 81 presentations at grower meetings organized by Extension agents and private industry, regulatory and advisory agency meetings, outdoor workshops, soil judging contests, and others. CBARC scientists and Extension Specialists authored seven refereed Extension publications and were co-authors on thirteen more and were authors or co-authors on 26 other outreach publications. They also have a total of 15 reports on Oregon Invests!. Richard Smiley began serving on the scientific advisory board for ENDURE, a coalition of 16 private and federal institutes in 10 European countries. ENDURE has the responsibility for improving the productivity of pest management research across the European Union, and for developing more efficient systems to transfer new plant protection information to farmers and farm advisors.

Tami Johlke, Bob Correa, and Stewart Wuest presented a session on the importance of soil for agriculture and how farmers are working to prevent soil erosion for Pendleton sixth-graders at Outdoor School.

Stewart Wuest visited Pendleton High School to discuss scientific experiments with Ms. Bixler's Advanced Biology classes.

Visitors

The Center hosted several special events, including numerous research and planning meetings. Visitors hosted by the staff at the center included:

Dwayne Buxton, Area Director, USDA-ARS, Albany, CA
Andy Hammond, Associate Area Director, USDA-ARS, Albany, CA
Bob Matteri, Assistant Area Director, USDA-ARS, Albany, CA
Jeff Van Houten, Deputy Area Director, USDA-ARS, Albany, CA

Seminars

Fran Pierce and Jose Chavez, Center for Precision Agricultural Systems, WSU-Prosser, *An Integrated Wireless Approach for Remote, Real Time Irrigation Monitoring and Control*, 15 February, 2006.

Phil Williams, PDK Grain, Victoria, B.C., Canada, *Near Infrared Spectroscopy: Principles and Practices*, 27-28 March, 2006.

Dr. Mark Tomer, USDA-ARS, Agricultural Land and Watershed Management Unit, National Soil Tilth Laboratory, Ames, Iowa, *Determining Environmental Effects of Conservation Practices in Watersheds*, 23 May, 2006.

Dr. Philippe Lucas, INRA, Le Rheu, France, *Application of disease epidemiology and wheat growth modeling in the design of integrated management of take-all disease*, 3 July, 2006.

Dr. Francoise Montfort, INRA, Le Rheu, France, *Application of biofumigation to pest management of carrot and potato*, 3 July, 2006.

Dr. Charles Yesudas, Southern Illinois University, *QTL Mapping for Disease Resistance in Soybean and Wheat*, 31 July, 2006.

Dr. Guiping Yan, Washington State University, *Molecular mapping of wheat and barely genes for resistance to stripe rust*, 8 August, 2006.

Dr. Xinshun Qu, Pennsylvania State University, *Molecular detection of potato pathogens and marker-assisted selection for disease resistance*, 11 August, 2006.

Liaison Committees

Chairpersons Larry Bishop and Ernie Moore led the Pendleton and Sherman Liaison Committees, respectively. In 2006, we fully implemented conversion to a joint OSU-ARS Liaison Committees for purpose of enhancing organizational synergy between CBARC and CPCRC. These Liaison Committees provide insightful guidance and recommendations on research directions, staffing needs, and facilities and equipment needs. They also provide a crucial communication link between growers and the research community. We encourage you to contact the Liaison Committee chairs with your concerns and suggestions for improvements regarding any aspect of the research centers.

Expressions of Appreciation

The staff expresses their appreciation to individuals, associations, and corporations that have given special assistance for the operation of experimental research plots during this past year, 2005-2006. The Oregon Wheat Commission continued to provide crucial funding to the OSU programs at the Center, and we gratefully acknowledge their generous support. We want also to express our sincere appreciation to those individuals, groups, and corporations who provided additional equipment, supplies, funds, and labor to help us carry out our mission. These include: Charles Betts, Sheldon King, Bill Jepsen, the Pendleton Flour Mills, Pendleton Grain Growers, Agrium, Bayer, and Monsanto. For continued support, we thank the Umatilla Soil and Water Conservation District- Bev Kopperud and Ray Denny, and the Board of Directors of Oregon Wheat Growers League- Tammy Dennee, Mike Noonan, Kevin Porter, Jeff Newtson, and Don Coats.

We also want to express our appreciation to those who donated labor, supplies, equipment, or funds for the Pendleton Station Field Day. These include:

Agri-Check
Nathaniel and Ann Anderson
BASF Corp.
Bayer Corp.
Bayer CropScience LP
Farm Credit Service
Main Street Cowboys
McGregor Co.
Mid-Columbia Bus Co.
Nichino America Inc.
Oregon Wheat Commission
Oregon Wheat Growers League
Pendleton Flour Mills
Pendleton Main Street Cowboys
Walla Walla Farmers Coop.
Western Farm Service
Wheatland Insurance
Wilbur-Ellis
Wildhorse Foundation

We also want to acknowledge and thank the donors who provided buses, meals, and other services for the Sherman Station Field Day at Moro, including:
Anipro
Bank of Eastern Oregon
Columbia River Bank
Farm Credit Services
Main Street Cowboys
Mid-Columbia Bus Co.
Mid Columbia Producers
Morrow County Grain Growers
Oregon Wheat Commission
Oregon Wheat Growers League
Richelderfer Air Service
Seed Prod +
Sherman Aviation
Sherman Farm Chemicals
Wasco Electric Coop
Wilbur-Ellis

The local county agricultural agents throughout north-central and northeastern Oregon have provided invaluable local assistance in locating research sites, coordinating activities with farmer-cooperators, and providing input to our research programs. These tireless individuals include Mary Corp, Clive Kaiser, and Don Horneck in Umatilla County; Darrin Walenta in

Union/Baker/Wallowa counties; Larry Lutcher in Morrow County; Sandy Macnab in Sherman County; Brian Tuck in Wasco County; and Jordan Maley in Gilliam County. County agricultural agents in Washington have also been key members of our team, and we wish to thank Paul Carter in Columbia County; Aaron Esser and Dennis Tonks in Adams/Lincoln Counties.

We wish to express special gratitude to the many regional producers who allowed us to work on their property during the past year (see separate listing). Not only have they performed field operations, loaned equipment, donated chemicals, forfeited yield, and adjusted their practices to accommodate our experiments, but they also voiced support for agricultural research at the local, regional, and national levels. The locations of these off-station plot sites are shown on the map that follows.

We gratefully appreciate the support and encouragement of growers, organizations, and businesses with missions common to ours: to serve in the best manner possible the crop production and resource conservation needs of our region. As we continue toward this goal, your suggestions on how we may improve our efforts are always welcome.

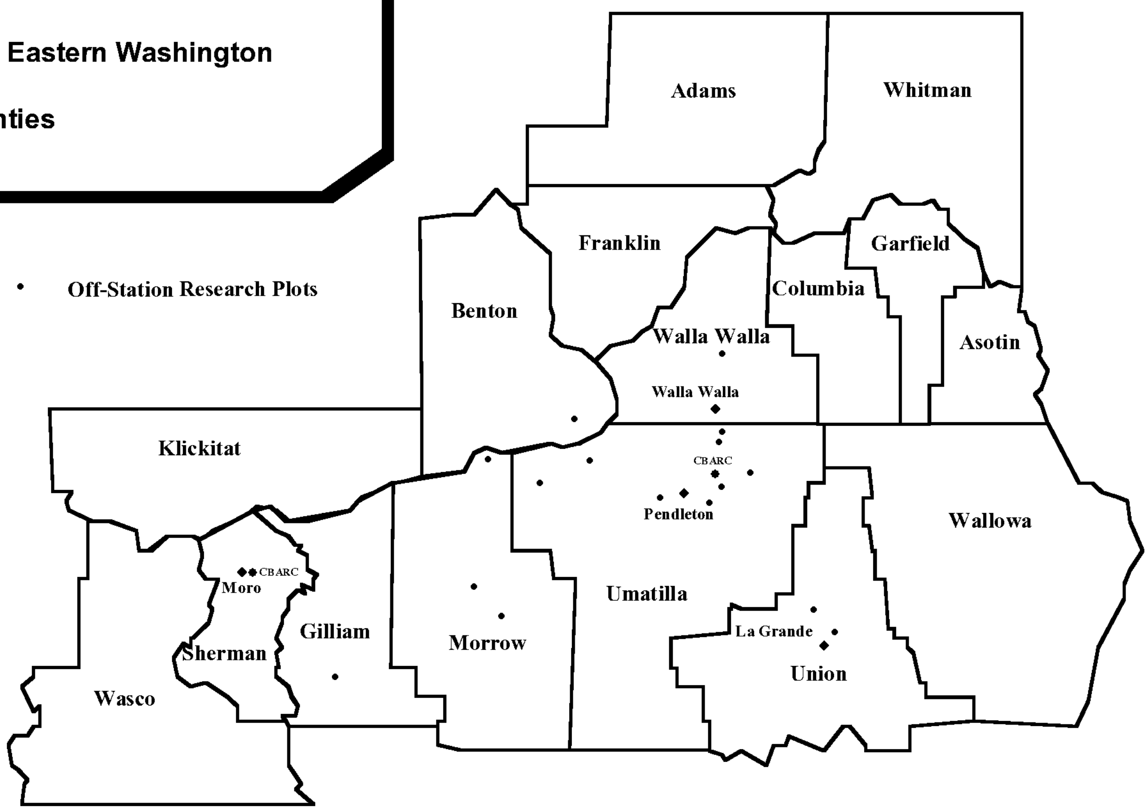
Steve Petrie
Superintendent
OSU-CBARC

Dan Long
Research Leader
USDA-ARS-CPCRC

RESEARCH PLOT LOCATIONS

Eastern Oregon - Eastern Washington

Counties



BENTON, WA
- Sunheaven Farms

GILLIAM, OR
- Gilliam County Wheat Lab

MORROW, OR
- Bill Jepsen
- Chris Rauch
- Alan Cleaver

UMATILLA, OR
- Elise Aquino
- D-8 Ranches
- Jim Duff
- Phil Hawman
- Bob Johns
- Mark Kirsch
- Don Lieuallen
- Robert Lieuallen
- Russell Lieuallen
- Kent Madison
- Herb Marsh
- Eric Nelson
- Jeff Newtson
- Kevin Porter
- Fred Price
- Clint Reeder
- Paul Reeder
- Bob Roselle

UNION, OR
- John Cuthbert
- Rod Case

Walla Walla, WA
- Ron Klassen

Research Center Publications

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Cereal Cyst Nematode: Distribution, Yield Reduction, and Crop Management Strategies

Richard Smiley, Jason Sheedy, Jack Pinkerton,
Sandra Easley, Alison Thompson, and Guiping Yan

Abstract

The cereal cyst nematode (*Heterodera avenae*) is widely distributed in the western United States. Regions known to be infested by this plant-parasitic nematode are reviewed. Samplings of infested fields revealed that infective juvenile stages of *H. avenae* reached peak densities during March in western Oregon (Washington County) and April in eastern Oregon (Union County). Winter and spring wheat were planted in three experiments to examine relationships between *H. avenae* and yield under dryland and irrigated conditions in moderately infested fields in eastern Oregon. Wheat yields were negatively correlated ($P < 0.05$) with densities of *H. avenae*. Wheat yield was also reduced significantly as the frequency of wheat increased from two to five crops in a five-year interval. Rotation of wheat with any broadleaf crop or with weed-free summer fallow greatly improved wheat yields compared to annual wheat. Populations of *H. avenae* in Oregon were identified as most similar to Pathotype Ha12. Reproduction of *H. avenae* was effectively eliminated by wheat genotypes carrying the *Cre1* gene that confers resistance to Pathotype Ha12. Additional resistance genes in wheat, barley, and oats were also identified. Current research is incorporating the *Cre1* gene into elite Pacific Northwest winter and spring wheat cultivars.

Key words: *Avena sativa*, cereal cyst nematode, genetic resistance, *Heterodera avenae*, *Hordeum vulgare*, *Triticum aestivum*, wheat, yield loss

Introduction

Nematodes are roundworms that occur worldwide in nearly all environments. Many nematode genera are beneficial to agriculture because they contribute to degradation of crop residue and are important members in the food chain. However, about 15 percent of the species are parasitic to plants and cause crop losses valued at $8 billion annually in the United States and $78 billion worldwide (Barker et al. 1998). Most plant-parasite nematodes are tiny (less than 1 mm or 0.04 inch long) and live in soil.

The cereal cyst nematode, *Heterodera avenae*, is distributed worldwide in temperate cereal-producing regions (Rivoal and Cook 1993, Nicol 2002, Nicol et al. 2003) and is easily spread to noninfested areas with soil carried on equipment, animals, shoes, or root, tuber, and ornamental crops. It also is dispersed by wind (in dust) and water. In North America, *H. avenae* was first reported in Ontario, Canada and, 30 years later, was found in most counties of that province. In the United States, *H. avenae* was first detected during 1974 in Washington County, western Oregon and is now known to be present in seven western states: California, Colorado, Idaho, Montana, Oregon, Utah, and Washington.

Cereal cyst nematodes attack only members of the grass family (Poaceae). They enter only the meristematic tissue near root tips and the feeding process causes different symptoms to occur on different cereal crops. Wheat roots become bushy, knotted, and shallow (Fig. 1 and 2), oat

Figure 1. Uniformly chlorotic and stunted third-year annual spring wheat caused by a combination of cereal cyst nematode and low fertility in Union County; extra nitrogen was applied along the field border (foreground).

Figure 2. Abnormal branching and shallow rooting symptoms observed on roots of most spring wheat plants collected from the field shown in Fig. 1.

Figure 3. Patchy winter wheat growth caused by cereal cyst nematode in Union County.

Figure 4. Comparison of plants from stunted and "healthy" areas of winter wheat field shown in Fig. 3.

roots become thickened and shortened, and barley roots exhibit no readily discernable symptoms. Leaf tips often become discolored: reddish-yellow on wheat, red on oats, and yellow on barley. Plants of each cereal crop may become stunted in patches (Fig. 3 and 4). Close inspection of roots and extraction of nematodes from roots and soil are required to confirm that *H. avenae* may be causing plant symptoms that often mimic other maladies such as nutrient deficiency, barley yellow dwarf virus, root rots caused by fungal pathogens, or drought stress at a time when soil water is not yet at a limiting level. Root damage by *H. avenae* often also favors greater colonization of roots by root-rotting fungal pathogens and by saprophytic bacteria, fungi, and non-plant-parasitic nematodes. These secondary organisms cause more intense rotting and discoloration than that caused by the plant-parasitic nematode itself.

The cereal cyst nematode consists of a complex group of closely related *Heterodera* species (*H. avenae*, *H. filipjevi*, *H. latipons*, and others). Specialized virulence groups called pathotypes occur within each species and are roughly equivalent to the "race" concept used to define virulence groups for the pathogens that cause rust diseases. At least 12 pathotypes have been described for *H. avenae*. Each pathotype is virulent to wheat unless a specific gene is present to nullify its virulence to that pathotype. Identities of the pathotypes present in the western United States were previously unknown. A clear understanding of the pathotype identity is required before one or more genes for resistance can be selected and used to improve the performance of wheat, barley, and oats planted on infested land. Resistant cultivars are a key component of effective integrated management strategies for cereal cyst nematodes and the other pathogens that generally coexist in the same soils.

Cyst nematodes complete only one life cycle each year. Adult females become nonmotile, feed exclusively from specialized cells inside the root, and remain attached to the root until after the root and the female have died. The female's body contains eggs that hatch when certain environmental conditions are met. Juvenile nematodes migrate into soil and infest the tips of young root segments.

Nematode detection and identification require the services of a professional nematologist. Directions for collecting and submitting samples are available from diagnostic laboratories or many extension service offices.

This paper summarizes current knowledge regarding the dissemination of *H. avenae*, yield losses associated with *H. avenae* under several management regimes, and efforts to produce resistant cultivars for use on infested fields. Crop management recommendations are discussed, with emphasis on crop rotations and genetic resistance.

Methods

Geographic distribution

Information on the distribution of *H. avenae* in the western United States is based mostly on anecdotal evidence. There have been no comprehensive surveys for cereal cyst nematodes that have included large numbers of nonirrigated fields. A survey capable of detecting cereal cyst nematodes was performed mostly on irrigated crops in southern Idaho and in two counties of eastern Oregon (Hafez et al. 1992). Smiley et al. (2005b, c), Strausbaugh et al. (2004), and directors of nematode diagnostic laboratories in Idaho and Nebraska have reported additional infestations based on more general samplings or on samplings at experimental sites where detection of cereal cyst nematodes was not anticipated.

Cereal cyst nematodes were extracted from soil, identified, and counted using the following procedure. A composite soil sample is collected from a sampling unit such as an entire field, a specific area of a field, or an experimental plot. Multiple (15 to 20) cores of soil are collected from the upper 8 to 12 inches of soil and combined for each composite sample. A subsample is removed from the larger sample and air-dried. Cysts are extracted from the subsample using a modified Fenwick can elutriation method and are separated further from the plant debris by flotation in an ethanol + glycerin solution (Caswell et al. 1985, Ingham 1994). Cysts are then picked from the remaining debris and crushed to determine numbers of eggs and juveniles. The moisture content of the air-dry soil is determined and numbers of eggs plus juveniles are then adjusted to reflect *H. avenae* density per pound of oven-dry soil.

Peak hatching period

The greatest risk to cereal crops coincides with the presence of high populations of infective juveniles in the soil. This event occurs shortly after eggs hatch to release juveniles inside the cyst. The juveniles move out of the cyst and into the soil where they may infest the tips of young root segments. Population dynamics of *H. avenae* infective juveniles in soil were determined at infested sites in two areas of Oregon. The site in western Oregon (Washington County) was at 850 ft in elevation among rolling hills. The area receives about 40 inches of rainfall annually and has a relatively mild climate comprised of warm, dry summers and cool, wet winters, generally without frozen soil. Soil at the Washington County site was a Laurelwood silt loam. The site in eastern Oregon (Union County) was located along the floor of a high-elevation valley (2,700 ft elevation). The region receives about 18 inches of rainfall annually and is characterized by a relatively harsh climate consisting of warm, dry summers and cold, wet winters that typically include several months of soil freezing. Mean daily air temperatures at this site are typically 30°F in January and 64°F in July and August. Soil at the Union County site was a Conley silty clay loam. Unplanted soil was sampled at approximately biweekly intervals from October 1977 through June 1978 in Washington County and from February through July 1988 in Union County. Soils were processed as described earlier.

Yield reduction

Associations between grain yield and the density of *H. avenae* in soil were determined by planting experimental plots with one or more cultivars of wheat and then correlating grain yield with the density of *H. avenae* in each plot.

Winter wheat: A 5-year crop rotation experiment involving 11 crop sequences was performed on a field at the Cuthbert Farm 6 miles northeast of La Grande, in Union County, Oregon. Soil was a poorly drained Conley silty clay loam overlying clay beginning at 12-inch depth. The low-land site used for this experiment had a perched water table (18-inch depth) for up to 5 months during winter and spring and was sprinkler irrigated to meet crop needs during the summer.

Detailed descriptions of crop sequences and management can be found in Smiley et al. (1994). Briefly, a field infested with *H. avenae* was managed as a winter wheat/summer fallow rotation for 6 years. During the spring following the 1986 harvest, wheat stubble was incorporated by moldboard plowing to 12-inch depth and disking to 4-inch depth. During mid-August 1987 the field was grid sampled at 200-ft intervals. At each grid point in the field, 15 to 20 cores of soil were collected to 8- to 12-inch depth and composited as a single sample. Cysts extracted from the grid samples yielded up to 9,545 eggs plus juveniles/lb of soil.

Treatments were established in 16- by 100-ft plots replicated four times in a randomized complete block design. The experiment started in autumn 1987 and terminated with wheat harvest in August 1992. Treatments included: 1) annual winter wheat (cv. 'Stephens') with seedbed prepared by deep plowing and disking, 2) annual winter wheat with stubble removed by burning and seedbed preparation by shallow mixing to about 1- to 2-inch depth with a skew treader or light disk, 3) winter wheat/summer fallow rotation with seedbed preparation by deep plowing and disking, 4) winter wheat following two successive years of cultivated summer fallow, 5) winter wheat/field pea (cvs. 'Moranda' or 'Columbia') rotation with seedbed preparation by deep plowing and disking, 6) two successive years each for winter wheat and field pea, 7) winter wheat/summer fallow/spring mustard (cv. 'Tobin') rotation with seedbed preparation by deep plowing and disking, 8) winter wheat/spring barley (cv. 'Steptoe')/summer fallow rotation with seedbed preparation by deep plowing and disking, 9) winter wheat following 3 years of weed-free alfalfa (cv. 'Blazer') and seedbed preparation by deep plowing and disking, 10) winter wheat following 3 years of an alfalfa crop moderately infested by grass weeds, and 11) winter wheat following 4 years of a Kentucky bluegrass (cv. 'Baron') seed crop.

Soil samples (described above) from each plot were collected annually following harvest in mid-August. Cysts were extracted from soil and the number of eggs plus juveniles contained in the cysts was quantified for each pound of oven-dry soil in the sample. The timing for the peak density of *H. avenae* juveniles in soil, described above, was monitored in the weed-free summer fallow phase of the winter wheat/summer fallow rotation during the first crop year of this experiment. Grain was harvested each year with a small-plot combine.

Spring wheat: Experiments with spring wheat were conducted on annually planted *H. avenae*-infested fields at the Cuthbert and Davis farms during 2002 and 2003, respectively. The Davis Farm is located 8 miles east-southeast of La Grande. Supplemental irrigation was applied to the experimental site at the Davis Farm but not at the Cuthbert Farm. At the Cuthbert Farm, the hill-slope location for this spring wheat experiment differed from the valley floor location used for the winter wheat experiment.

Soil at the experimental site on the Cuthbert Farm was a deep, well-drained Imbler fine sandy loam. Following a perennial mint crop, the field was plowed, disked, and planted to winter wheat during October 2001. Winter wheat within the intended experimental area was killed by glyphosate herbicide during mid-March 2002. On April 14, spring wheat for the experiment was planted without tillage using a double-disk plot drill equipped with a cone-seeder and five openers at 12-inch row spacing. A single cultivar of spring wheat (cv. 'Zak') was planted into 18 plots (11 by 30 ft).

Soil at the Davis Farm was a well-drained Hoopal fine sandy loam. The site was not tilled or planted to an over-winter crop following the 2002 wheat harvest. Volunteer vegetation was killed by glyphosate herbicide during mid-March 2003, 1 month before planting. Fertilizer was applied as a surface broadcast. Spring wheat was planted directly into stubble during mid-April. Wheat was planted into 36 plots (5.5 by 30 ft) with the drill described earlier. Nine replicates were planted for each of four Australian cultivars: 'Frame', 'Molineux', 'Ouyen', and 'Spear'. The cultivar 'Ouyen' carries the *Cre1* gene for resistance to *H. avenae*, the cultivars 'Frame' and 'Molineux' carry the *Cre8* resistance gene, and 'Spear' is susceptible. Soil samples were collected before planting and after harvest, and again in the spring of 2004. Grain was harvested in mid-August with a small-plot combine.

Statistical analysis: All nematode population and yield data were analyzed by analysis of variance for the randomized complete block model. When treatment effects were significant at $P < 0.05$, means were separated using the least significant difference test. Variables were also evaluated by regression analysis using a linear model.

Pathotype

The identity of the *H. avenae* pathotype in eastern and western Oregon was determined by evaluating the potential of a nematode population to reproduce (form new cysts) on entries of an International *Heterodera avenae* Test Assortment consisting of 12 barley, 6 oat, and 6 wheat lines, called differentials.

The western Oregon population was screened at Corvallis during 1988 using the differentials described and provided by Drs. S. Andersen and K. Andersen (1982; Agricultural University, Copenhagen, Denmark). Soil was collected from an infested field in Washington County and incubated in Baermann funnels (Ingham 1994) until adequate numbers of *H. avenae* juveniles became available to inoculate test soils in the greenhouse. Plastic tubes were filled with a 1:2 mixture of loam plus sand. A seed of each differential was planted into each of seven replicate tubes. One hundred *H. avenae* juveniles were placed into each tube immediately after seed was planted and four more times at 3-day intervals. Plants were harvested after 8 weeks of growth in the greenhouse. Numbers of cysts on roots and in soil were counted and results were used to classify plants as either resistant or susceptible. The resistant category was assigned if the number of cysts was less than 5 percent of the total number of cysts observed on the fully susceptible differentials. The pathotype was identified by matching experimental results with the published matrix of pathotype by differential reactions (Andersen and Andersen 1982).

The eastern Oregon population of *H. avenae* was screened at Pendleton during 2006. The International Test Assortment was acquired from the Nordic Gene Bank (Alnarp, Sweden). Soil was collected in March 2005 from an infested field in Union County and mixed thoroughly to assure uniformity. The mixed soil contained 610 *H. avenae* eggs plus juveniles/lb of soil. Soil was placed into Styrofoam cups, watered, and incubated for 10 days. Weeds and volunteer wheat were removed before planting entries from the International Test Assortment. Three screening procedures were used during 2005; one in the greenhouse and two in an outdoor sand-bed nursery. The greenhouse test was planted on May 20 and tests in the sand-bed were planted on March 21 ("early" test) and again on April 4 ("late" test). Numbers of cysts on roots and in soil were counted 9 and 10 weeks after planting in the greenhouse and sand-bed, respectively. Assignment of resistant or susceptible reactions was as described above, using the matrix of reactions published by Rivoal and Cook (1993).

Genetic resistance

Seed of at least 50 potentially useful gene-donor lines of wheat were imported from breeding programs at the International Maize and Wheat Improvement Center (CIMMYT) and in Australia and France. These acquisitions included germplasm that carries all except two of the nine currently described genes for resistance to *H. avenae*: *Cre1*, *Cre2*, *Cre3*, *Cre5*, *Cre7*, *Cre8*, and *CreR*. The collection at Pendleton now only lacks germplasm carrying the *Cre4* and *Cre6* genes, both of which are currently being acquired, making it the most advanced collection for *H. avenae* resistance genes in the United States. Some *H. avenae*-resistant lines acquired from CIMMYT reportedly carry genes for tolerance to drought as well as resistance to root-lesion nematodes and/or Fusarium crown rot.

Genotypes carrying the resistance genes were tested against the eastern Oregon population of *H. avenae* during the pathotyping studies, described above.

Results and Discussion

Geographic distribution

Heterodera avenae is now known to be distributed across many small grain-producing regions in the western United States. The following information is abbreviated from reports summarized by Smiley et al. (1994, 2005d).

In the United States, *H. avenae* was first detected on oats in a high-rainfall (40 inch/year) region of western Oregon (Washington County) during 1974 (Fig. 5). This nematode was next

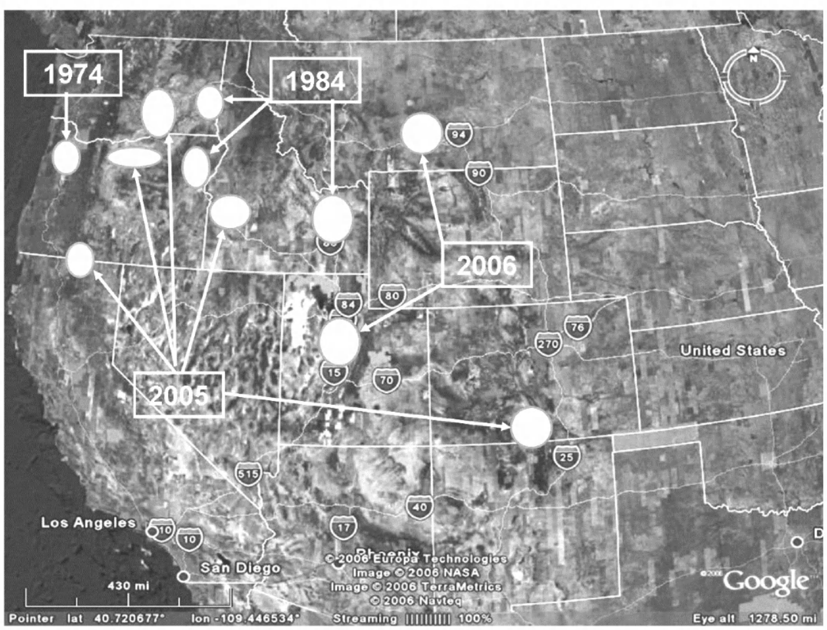

Figure 5. Location and year in which infestations of *Heterodera avenae* were publicly reported in the western United States.

identified in a wheat field in southern Whitman County, Washington during 1983, representing the high-precipitation (24 inch/year) edge of the primary wheat belt in Oregon and Washington. During 1984, *H. avenae* was reported from irrigated barley fields in Parker and Fremont counties in southeastern Idaho and was detected on irrigated oats in Union County in eastern Oregon. Three years later, in 1987, two-thirds of all cultivated dryland (rainfed) and irrigated fields sampled in Union County were found to be infested with *H. avenae*. In 1990, dissemination of *H. avenae* from Union County to irrigated fields in north-central Oregon (Morrow County) was documented; cysts were in soil transported with seed potatoes grown in rotation with wheat on fields infested with *H. avenae*. The known distribution was extended in 1992 to include irrigated wheat fields in three additional counties in southeastern Idaho and Baker County in eastern Oregon. *Heterodera avenae* has now been detected in western Idaho, southern Oregon (Klamath County), northern California (Modoc/Siskiyou County), central Washington, north-central Oregon, and south-central Colorado. During 2006, central Utah and central Montana were added to the list of publicly reported infestations (personal communication, Dr. Tom Powers, University of Nebraska, Lincoln). All of the *H. avenae* infestations reported above are thought to occur in irrigated fields or in dryland fields in areas with 24 to 40 inches annual precipitation.

Eighty percent of the wheat production area in Oregon and Washington is on dryland fields in areas receiving 10 to 16 inches annual precipitation. Low densities of *H. avenae* were recently also reported on dryland wheat in 10- to 12-inch precipitation zones in Sherman and Umatilla counties of Oregon (Smiley et al. 2005d).

While it is clear that *H. avenae* is present in each of the diverse environments and management systems for wheat in the Pacific Northwest, the extent of infestation remains unknown, especially in nonirrigated soils because nematodes are rarely sampled from dryland fields. Even if nematodes are sampled the focus is generally on motile forms such as root-lesion nematodes rather than on nonmotile cysts of species such as *H. avenae*. Detection of motile forms and cysts requires two entirely different soil processing methods, at twice the expense. Cysts of *Heterodera* and related genera therefore have been extracted only occasionally in nematode diagnostic laboratories, particularly for samples submitted from nonirrigated cropping systems. In addition to minimal efforts to detect *H. avenae* in dryland soils, it is unlikely that they could be detected where they occur in a patchy distribution pattern unless samples are collected from areas where wheat growth is stunted for otherwise unknown reasons.

An improved understanding of *H. avenae* infestation in dryland environments is becoming increasingly important. The dominant cropping system for dryland cereal crops in the region has been a 2-year rotation of winter wheat and summer fallow. The summer fallow system is prone to socio-economic concerns such as soil erosion, declining quality of soil, and reduced quality of water and air. Rotation to a broadleaf crop is often not economically acceptable to many dryland wheat and barley producers. These factors and Federal farm programs have encouraged producers to explore farming systems that are more sustainable. Plantings of winter wheat in the wheat-fallow rotation continue to decline in Oregon and Washington. The percentage of spring wheat acreage planted without tillage, and usually without rotation to a broadleaf nonhost, was 2 percent in 1990 and 20 percent in 2004 (Smiley et al. 2005a). In some counties there has been as much as a 35 percent increase in area planted to no-till spring wheat. *Heterodera avenae* is capable of causing severe damage when wheat is produced annually on infested fields. For instance, a severely infested third-year annual spring wheat crop in Union County, Oregon had to be plowed under without harvesting because of extreme damage by *H. avenae* (Smiley, personal observation).

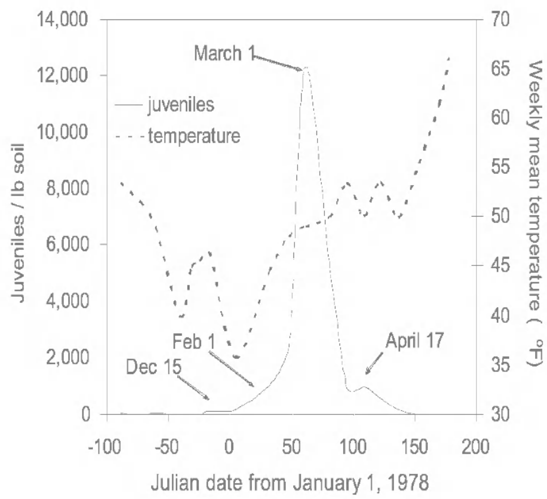

Figure 6. Density of *Heterodera avenae* juveniles in soil at approximately biweekly intervals in unplanted soil in Washington County, Oregon during the fall of 1977 and spring of 1978.

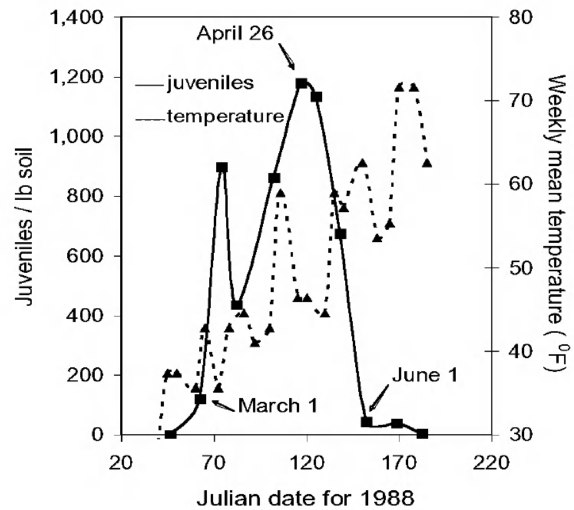

Figure 7. Density of *Heterodera avenae* juveniles in soil at approximately weekly intervals under winter wheat in a winter wheat/summer fallow rotation in Union County, Oregon during the spring of 1988.

Peak hatching period

Very few juveniles were detected in soil during the fall and winter in western Oregon (Washington County). Weekly mean air temperatures declined to a low of 36°F during January. Populations of infective juveniles began to increase rapidly during February, peaked during early March, and declined to very low numbers by late April (Fig. 6). The onset of hatching and the period of peak juvenile populations in soil coincided with mean weekly air temperatures that increased from about 40°F to 50°F.

In eastern Oregon (Union County), soil sampling began when the mean weekly air temperature was less than 32°F (Fig. 7) and the soil surface was still frozen. By late February the soil profile had thawed but shallow freeze-thaw cycles continued at the surface until early April. Populations of *H. avenae* juveniles in soil increased rapidly 2 weeks after mean weekly air temperature stabilized between 36 °F and 40°F. Peak populations of juveniles occurred following a spike in weekly mean air temperature to 60°F in mid-April. Air temperature declined to 50°F to 60°F in late-April and then increased to 72°F by late June. Numbers of juveniles declined in May to barely detectable levels by June 1. Adult males were first detected on 1 June.

Hatching of *H. avenae* in Oregon during early spring was similar to that of the northern ecotype described by Rivoal (1986). Since the greatest damage from *H. avenae* occurs when the nematode invades root tips during the early seedling stage (Simon and Rovira 1982), the peak hatching period during the spring presents a much greater level of risk to spring wheat than to winter wheat.

Yield reduction

Detailed accounts of relationships between wheat yield and populations of *H. avenae* in Union County are found in Smiley et al. (1994, 2005d). At the Cuthbert Farm the average initial density of *H. avenae* eggs and juveniles in 1988 was 13,636/lb of soil. Each year, yield of winter wheat was negatively correlated with the population of *H. avenae*. This relationship is illustrated for the crop harvested in 1990 (Fig. 8).

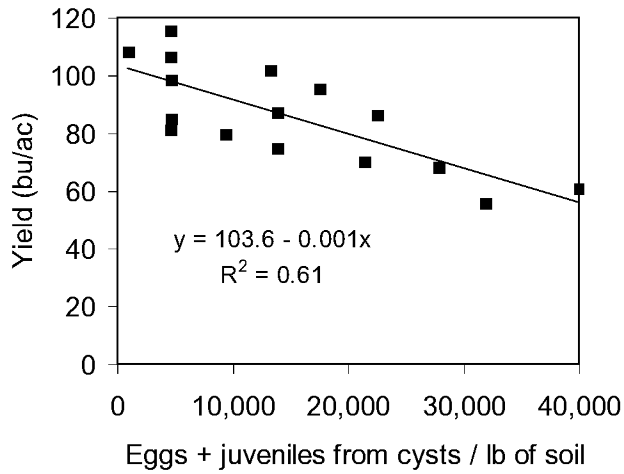

Figure 8. Relationship between the preplant density of *Heterodera avenae* (eggs + juveniles from cysts sampled in September 1989) and grain yield for annual irrigated winter wheat cv. 'Stephens' at the Cuthbert Farm during 1990.

Average density of *H. avenae* eggs and juveniles prior to planting spring wheat was 1,079/lb of soil at the Cuthbert Farm in 2002 and 768/lb of soil at the Davis Farm in 2003. Yield of spring wheat was negatively correlated with the initial *H. avenae* density at each site (Figs. 9 and 10). Compared to the maximum *H. avenae* initial density detected in these field experiments, a 10-fold higher population (145,000/lb of soil) was detected at a "hot spot" in another Union County field. Recrop spring wheat has been uniformly and totally destroyed by this nematode in at least a few commercial fields in eastern Oregon (Fig. 1).

Crop management practices

Yields for winter wheat following summer fallow or broadleaf crops at the Cuthbert Farm were nearly double the yields achieved with annual winter wheat (Fig. 11). Based on the following lines of evidence, we concluded that the yield difference was caused by damage from *H. avenae* rather than by other agronomic consideration. Wheat yields in the various rotations were always inversely correlated with populations of *H. avenae*. Water was not an experimental variable due to the perched water table during winter and spring, and supplemental irrigation during the summer and fall. Fertilizer was applied based on soil tests and anticipated yields, and was not thought to be limiting for wheat productivity in any of the crop sequences. Yields for annual winter wheat and for wheat in any other crop rotation containing barley or grassy weeds were statistically lower than for all weed-free crop rotations, including wheat-fallow rotation, wheat-pea rotation, wheat-fallow-mustard rotation, and wheat following 3 years of weed-free alfalfa. There also was a direct relationship between reduction in yield and an increasing frequency of host crops (wheat, barley, or weed grasses) planted or allowed to grow during the 5-year cropping interval (Fig. 12).

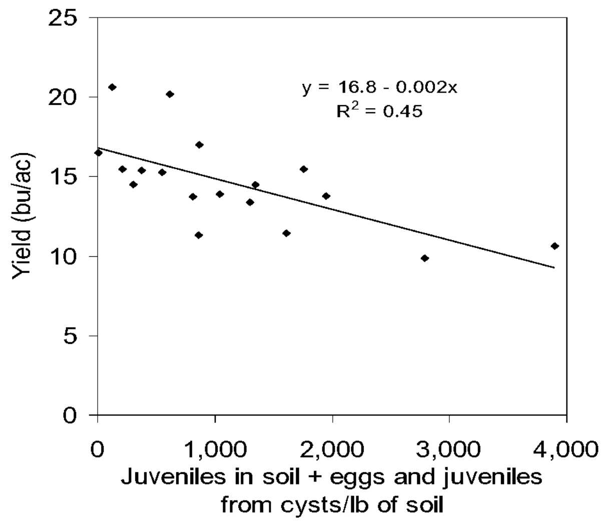

Figure 9. Relationship between the preplant density of *Heterodera avenae* (juveniles in soil and eggs + juveniles from cysts) and grain yield for dryland spring wheat cv. 'Zak' that followed a perennial mint planting at the Cuthbert Farm during 2002.

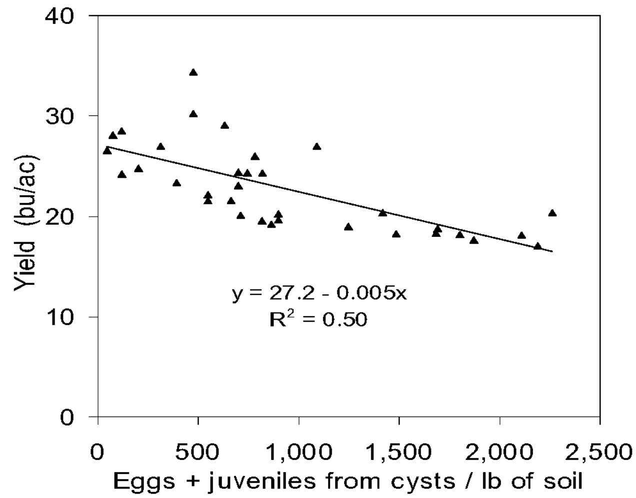

Figure 10. Relationship between the preplant density of *Heterodera avenae* (eggs and juveniles from cysts) and grain yield for irrigated spring wheat 'Zak' at the Davis Farm during 2003.

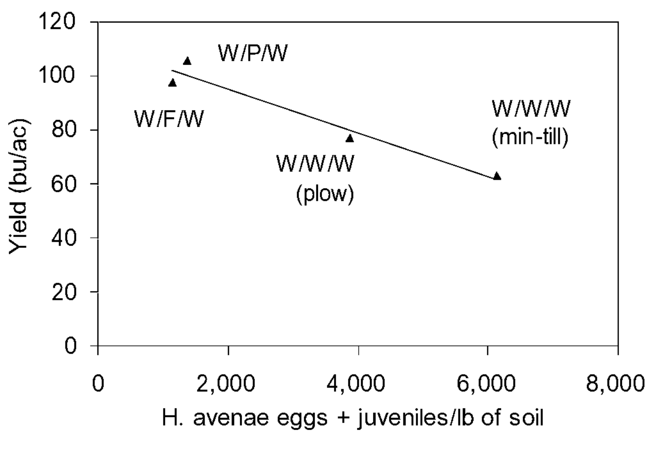

Figure 11. Relationship between yield of winter wheat cv. 'Stephens' and the density of *Heterodera avenae* (eggs + juveniles from cysts) after harvesting annual winter wheat (W/W/W) in plowed or minimum-till soil, or following summer fallow (W/F/W) or peas (W/P/W) in plowed soil at the Cuthbert Farm during 1990.

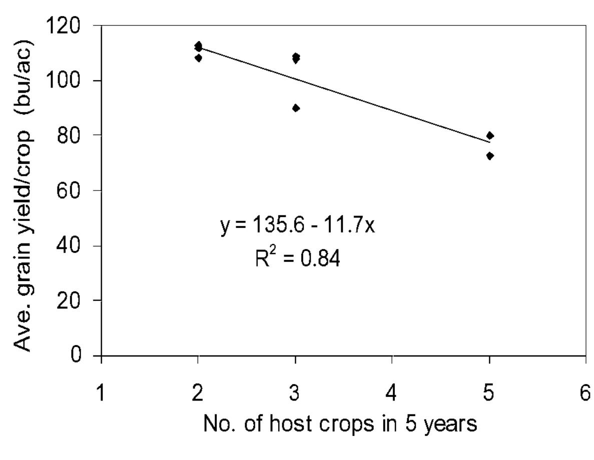

Figure 12. Relationship between average grain yield for winter wheat cv. 'Stephens' crops in various crop rotation sequences and the frequency of winter wheat during a 5-year rotational sequence at the Cuthbert Farm, 1988-1992.

Reducing the frequency of host crops in the rotation by rotating wheat, barley, or oats with broadleaf crops or weed-free summer fallow is a well established practice for reducing damage from *H. avenae* (Rovira et al. 1981, Rovira and Simon 1982, Brown 1987, Rivoal and Saar 1987). Our results are therefore consistent with reports elsewhere in the world. However, rotations in the Pacific Northwest are economical mostly in irrigated crops and in dryland crops produced in higher rainfall districts. Broadleaf rotation crops are generally not an economically viable option in the driest areas of the "wheat belt" in semiarid eastern Oregon and Washington.

Nematicides are not registered for application to wheat in the United States and there are no biological control measures or seed treatments known to be effective under field conditions. Management of *H. avenae* in the United States will be accomplished most efficiently through genetic resistance. Noninfested fields can be protected from becoming infested by sanitary practices that prevent infested soil from being introduced into "clean" land.

Pathotype

The *H. avenae* pathotypes in eastern and western Oregon are nearly identical. Results indicated that these populations are most like Pathotype Ha12 (Andersen and Andersen 1982, Rivoal and Cook 1993). While these populations do not fit with absolute certainty into the pathotype classifications published in 1982, international research has greatly expanded during the past two decades and it is no longer unusual to find populations that don't fit "exactly" into the rigid categories described in 1982 (Rivoal et al. 2001). Entries in the International Test Assortment are currently being revised but the updated test matrix is not yet available. Populations that react similarly but not exactly with the originally described pathotypes are currently accepted as evidence that the closely related populations are very likely to respond to the same resistance gene as the formally described pathotype. Results of the 1998 and 2006 pathotype studies suggest that the cereal cyst nematode populations in eastern and western Oregon are of the same origin and are most closely related to Pathotype Ha12 populations from northern European countries. Additional tests are planned to identify pathotype(s) present in other western states.

Genetic resistance in wheat

Genotypes carrying the single dominant *Cre1* gene for resistance to Pathotype Ha12 were tested against the eastern Oregon cyst nematode population. Screening was performed in the greenhouse and in the outdoor sand-bed facility. Two genotypes (AUS 10894 and 'Ouyen') carrying the *Cre1* gene both resulted in a resistant reaction in both tests, meaning that very little nematode reproduction occurred on those lines. 'Ouyen' is a released Australian hard-white spring wheat cultivar with good agronomic traits such as high grain yield and quality, and is a desirable *Cre1* gene-donor parent for crossing with cultivars adapted to the Pacific Northwest environment. Testing as a fall-planted cultivar during 5 years at Pendleton and at Lind, Washington has indicated that 'Ouyen' is as winter hardy as 'Stephens' and 'Gene'. Field tests in *H. avenae*-infested soil in Union County during 2003 also showed that the yield of 'Ouyen' was less responsive to application of a nematicide compared to cultivars carrying the *Cre8* gene or having no genes for resistance to this nematode.

Wheat lines carrying *Cre2*, *Cre3*, *Cre5*, *Cre7,* and *Cre8* genes were also tested against the eastern Oregon population of *H. avenae*. Lines with *Cre3*, *Cre7,* and *Cre8* were categorized as susceptible due to efficient reproduction of the nematode on those lines in each of the tests. Lines with *Cre2* and *Cre5* were categorized as moderately resistant (allowing only moderate nematode reproduction) to *H. avenae* in our greenhouse test. Reproduction of the nematode on *Cre5* was somewhat higher in the sand-bed nursery than in the greenhouse, leading to a susceptible rating in the outdoor nursery. Nevertheless, it may be important that *Cre5* provided evidence for suppressing *H. avenae* reproduction in some instances. This gene is carried by the French cultivar 'VPM 1' and many of its derivatives, which are the cultivars expressing resistance to the eyespot disease (strawbreaker foot rot). In France, 'VPM 1' was previously reported as moderately resistant to *H. avenae* Pathotype Ha12 (Jahier et al. 2001).

Genotypes carrying the *Cre1* gene need to become the focal point for further research in Oregon. In 2007, crosses are being made between 'Ouyen' and the Pacific Northwest-adapted soft-white winter wheat cultivars and lines 'Stephens', 'Tubbs 06', 'Brundage 96', ORSS-1757, ORH010085, and ORH010920, and the spring wheat cultivars 'Louise' (soft white), and 'Otis' (hard white). The resulting F1 populations will be back-crossed to the same locally adapted parents during 2008. Molecular markers for the *Cre1* gene were developed in Australia (Williams et al. 1994, Ogbonnaya et al. 2001) and should prove to be an important tool in marker-assisted selection procedures that will increase the productive efficiency of this wheat breeding program. Resistant cultivars are expected to improve productivity where high-risk cropping systems are otherwise preferred in areas infested by this plant-parasitic nematode.

The Oregon State University Plant Pathology Program at Pendleton is a member of a newly developed International Cereal Cyst Nematode Initiative (ICCNI). The goal of ICCNI is to expand the level of knowledge regarding these nematodes and to improve crop management strategies and to train scientists capable of performing research on this topic. The program at Pendleton recently began serving as the introduction station and North American distribution center for germplasm in CIMMYT's Root Disease Testing Nurseries. We have distributed seed from the first two nurseries to wheat breeders at nine locations in the western and north-central United States. Four additional nurseries are currently being processed through quarantine and seed increase procedures at Pendleton.

Genetic resistance in barley and oats

Our research provided additional information that may be of particular interest and value to barley and oat breeders and producers. We detected *H. avenae* resistance in one barley and three oat lines, and moderate resistance in one oat, three barley, and two additional wheat lines. Most of the barley and oat lines are older, unimproved entries in the International Test Assortment. Nevertheless, these potential donor parents could prove useful in locations where these crops have been damaged by *H. avenae*, such as oats in western Oregon and malting barley in Colorado.

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Predicting Wheat Nitrogen Status with Remote Sensing

Jan Eitel and Dan Long

Abstract

Vegetation indices computed from remote sensing data containing the red edge region (690-730 nm) can be used to predict plant nitrogen (N) status. The earth imaging firm RapidEye™ plans to provide multispectral imagery that will include a red edge band in 2007. A field experiment was conducted to assess whether simulated RapidEye™ data could match the capacity of narrow-band, hyperspectral data to predict mid-season N status of dark northern spring wheat (*Triticum aestivum* L.). Ground-based spectroradiometer data were converted to the band equivalent reflectance of RapidEye™. Spectral indices were computed from resulting hyperspectral and multispectral data. Predictions of leaf chlorophyll and leaf N levels from linear regressions between ground data and the Modified Chlorophyll Absorption Ratio Index/Modified Triangular Vegetation Index (MCARI/MTVI) gave the highest r^2 values for chlorophyll, amounting to 0.69 ($P < 0.01$) for hyperspectral and 0.77 ($P < 0.01$) for multispectral. For leaf N, r^2 values were 0.68 ($P < 0.01$) for hyperspectral and 0.56 ($P < 0.01$) for multispectral. These results suggest that the MCARI/MTVI index computed from RapidEye™ data is a potentially useful predictor of mid-season wheat N status.

Keywords: crop nitrogen, in-season nitrogen management; spectral indices; wheat

Introduction

Recently, optical sensing of crop canopy spectral reflectance from ground-, aircraft-, and satellite-based platforms has been proposed for identifying the crop nitrogen (N) deficient portions of whole fields, and directing site-specific fertilizer applications (Raun et al. 2002). This approach promises to overcome limitations of field-based sampling methods that employ plant tissue testing and leaf chlorophyll measurements. Investigations of spectral characteristics associated with crop N status have relied upon the observed variation in strength of chlorophyll absorbance in the visible (450-690 nm) region of the electromagnetic spectrum (Yoder and Pettigrew-Crosby 1995). Changes in absorption properties in the "red edge" region (690-730 nm) also have been found to be related to changes in plant N status (Daughtry et al. 2000).

A wide variety of chlorophyll indices have been developed to maximize the relationship between the measured spectral response and plant N status. Many of these indices employ narrow band (hyperspectral) data that include bands within the red edge region (Daughtry et al. 2000, Haboudane et al. 2002). However, few satellite systems have bands in the red edge region, and their low spatial and temporal resolution further limits their use for predicting crop N status (Moran et al. 1997). In 2007, the commercial provider RapidEye™ (Brandenburg, Germany) will provide broad band (multispectral) satellite data containing a red edge band (Band 4: 690 – 730 nm) and worldwide daily coverage with a pixel resolution of 5 m, and thus may provide information for crop N management within the growing season. The objective of this study was to evaluate the suitability of chlorophyll indices derived from RapidEye™ multispectral data for predicting the N content and chlorophyll of spring wheat during mid-season.

Methods

Field Measurements

Relationships between crop spectral reflectance and nitrogen-related attributes were investigated within a dryland field planted to dark northern spring wheat (DNS) near Potlatch, Idaho (27 acres). Smaller areas of the crop that differed in degree of greenness were visually identified from the ground. Dark green areas tended to have above-average crop growth and biomass whereas lighter green areas had below-average growth and biomass. The crop was sampled for chlorophyll and N contents during mid-season before canopy closure (early heading stage). Sampling locations were chosen using a stratified random sampling scheme, with dark or light crop greenness representing the stratification variable. An equal number of plots (3 by 3 m in size) were randomly placed within dark green or light green areas, and totalled 42. To estimate leaf chlorophyll concentration within each plot, relative measurements of leaf chlorophyll (SPAD chlorophyll) were obtained from 30 randomly selected flag leaves using a Minolta SPAD 502 (Spectrum Technologies, Inc.) chlorophyll meter. Furthermore, flag leaf N estimates were obtained for each plot by randomly collecting 30 flag leaves, which were analysed in the laboratory for N concentration by using an automated dry combustion instrument, or Dumas procedure (Thermo Finnigan Flash 1112 Series). The flag leaf N and chlorophyll concentrations of a plot were taken as the average of the 30 measurements.

Canopy spectra were acquired under cloud-free conditions with an ASD FieldSpec® Pro (Analytical Spectral Devices, Inc.) spectroradiometer that measures surface radiance in 2,150 spectral bands. Spectra were taken between 11:00 a.m. and 3:00 p.m. to minimize effects of illumination geometry. The fibre optic probe of the spectroradiometer with a 25° field of view was held approximately 1.2 m at nadir. The spectral reflectance of each plot was the average of 20 discrete spectra obtained with the fibre optic probe at each of 20 points equally spaced on the circumference of a 2-m-diameter circle. Spectral measurements at each plot location were preceded by a dark current measurement and a white reference panel was used to convert radiance values into reflectance.

Spectral Indices and Data Analysis

The band equivalent reflectance (BER) provides a diagnostic indication of potential sensor performance (Smith et al. 2005). Hyperspectral reflectance data were convolved with the spectral response functions of each RapidEye™ band as needed to compute BER:

$$R_x = \sum_{i=\lambda_{\min}}^{\lambda_{\max}} r_i \rho_i \Big/ \sum_{i=\lambda_{\min}}^{\lambda_{\max}} r_i \qquad (1)$$

where R_x is BER for band x, λ_{min} is starting wavelength of band x's filter function, λ_{max} is ending wavelength of band x's filter function, r_i is relative response for band x at wavelength i, and ρ_i is reflectance measured by spectroradiometer at wavelength i (Trigg and Flasse 2000). The Modified Chlorophyll Absorbtion Reflectance Index (MCARI) and this index in ratio with the Modified Triangular Vegetation Index were computed from both real hyperspectral and band equivalent multispectral data (Table 1). Simple linear regression was used to determine the relationship between each spectral index and SPAD chlorophyll, or flag leaf N. The coefficient of determination (r^2) was used to compare the performance of the vegetation indices. Relationships were considered statistically significant at a probability level $P < 0.05$.

Results and Discussion

The combined index derived from MCARI and MTVI in ratio was more highly correlated with flag leaf N and SPAD chlorophyll than MCARI alone (Table 2). For flag leaf N, r^2 values were 0.68 for hyperspectral-based MCARI/MTVI versus 0.56 for multispectral-based MCARI/MTVI. Regarding chlorophyll, r^2 values were 0.69 for hyperspectral MCARI/MTVI versus 0.77 for multispectral MCARI/MTVI. A scatter plot of SPAD chlorophyll vs. MCARI/MTVI for multispectral data illustrates a linear, inverse relationship (Fig. 1). These findings agree with previous studies showing that combinations of chlorophyll indices and structural indices are superior to single chlorophyll indices because the former are able to account for variations in leaf area index and soil background (Daughtry et al. 2000; Haboudane et al. 2002, 2004). The r^2 values for multispectral data are slightly less in magnitude than those for hyperspectral data, indicating that the information loss from use of broadband multispectral data is small.

Conclusion

The preliminary results of this study suggest that multispectral data provided by the new RapidEye™ satellite series may be used to predict mid-season leaf N or chlorophyll status in dryland wheat. Growers could use this information to decide whether supplemental N fertilizer is needed within the growing season to improve grain quality of hard red wheat. Further research is needed to verify these results and determine the effects of atmosphere, and spatial and spectral resolution on crop reflectance measurements quantified from RapidEye™ image data.

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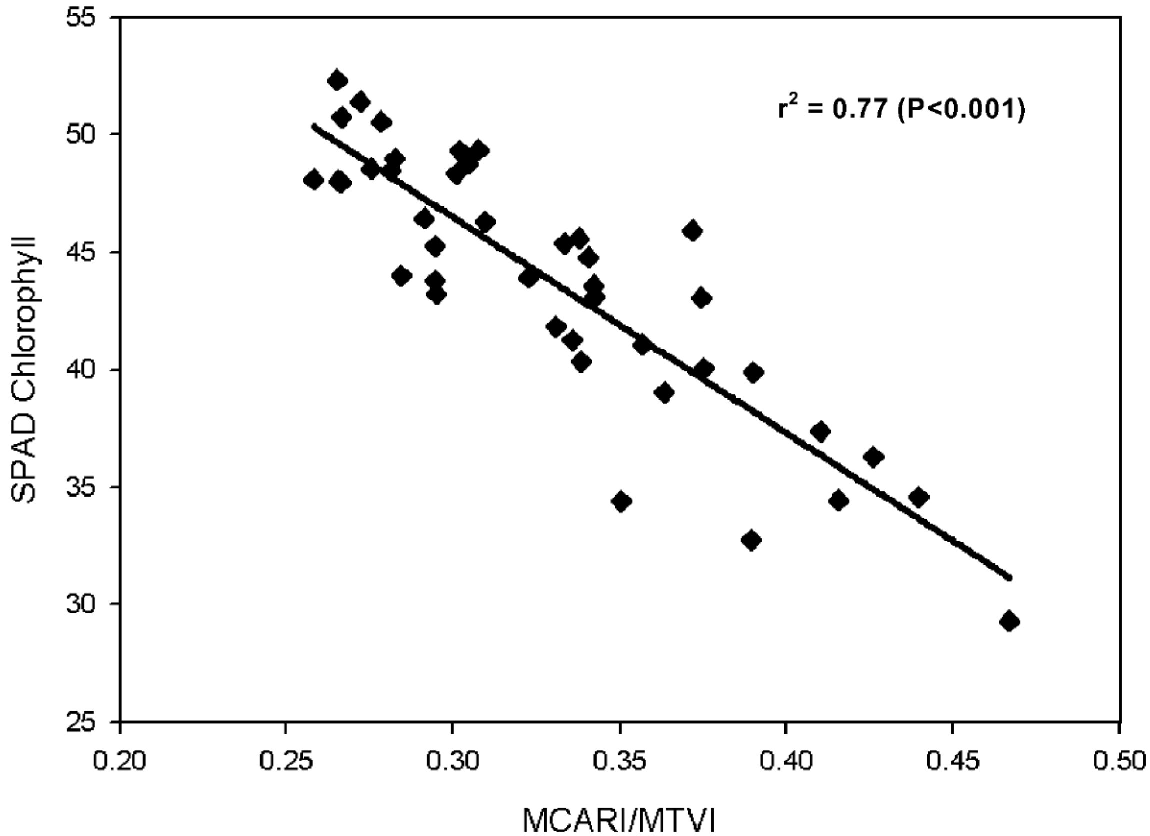

Figure 1. Scatter plot of SPAD chlorophyll versus the combined index MCARI/MTVI for multispectral data obtained from the dark northern spring wheat field near Potlatch, Idaho.

Table 1. Spectral indices and combined indices used in this study.

Vegetation index	Equation[a]	Reference
Modified chlorophyll absorption reflectance index (MCARI)	$MCARI(h) = [((R_{700} - R_{670}) - 0.2)(R_{700} - R_{550})](R_{700}/R_{670})$ $MCARI(m) = [((R_{band4} - R_{band3}) - 0.2)(R_{band\,4} - R_{band\,2})](R_{band\,4}/R_{band\,3})$	Daughtry et al. (2000)
Modified triangular vegetation index (MTVI)	$MTVI(h) = 1.5[1.2(R_{800} - R_{550}) - 2.5(R_{670} - R_{550})] / [(2R_{880} + 1)2 - (6R_{800} - 5\,R_{670}^{½}) - 0.5]^{½}$ $MTVI(m) = 1.5[1.2(R_{band5} - R_{band2}) - 2.5(R_{band3} - R_{band2})] / [(2R_{band5} + 1)2 - (6R_{band5} - 5\,R_{band3}^{½}) - 0.5]^{½}$	Haboudane et al. (2004)
Combined index	MCARI(h) / MTVI(h) MCARI(m) / MTVI(m)	Haboudane et al. (2002)

[a] (h) denotes indices employing hyperspectral data and (m) denotes indices employing multispectral data.

Table 2. Coefficient of determination (r^2) for spectral indices used as regression estimators of flag leaf nitrogen and SPAD chlorophyll.

Spectral Indices	Hyperspectral	Multispectral
	r^2	r^2
	Flag leaf nitrogen	
MCARI	0.20	0.01
MCARI/MTVI	0.68	0.56
	SPAD chlorophyll	
MCARI	0.43	0.08
MCARI/MTVI	0.69	0.77

Agronomic Performance of Food Barley at Pendleton and Moro

Steve Petrie, Patrick Hayes, Andrew Ross, Juan Rey, Karl Rhinhart, and Ann Corey

Abstract

Winter wheat is the predominant crop in the dryland Pacific Northwest, especially in the low (less than 12 inch) and intermediate (12-18 inch) rainfall zones that characterize much of the region. Growers and researchers alike have sought to develop other crops in these agronomic zones for at least 90 years without success. Winter and spring barley are potential alternative crops for much of the low and intermediate rainfall areas where fallow is practiced to minimize the potential for barley to contaminate wheat. The Beta-glucan (β-glucan) in barley offers specific health benefits to consumers and newly developed lines of barley with higher β-glucan concentration may offer growers an opportunity for a successful alternative crop. The objective of this research was to identify well adapted varieties or lines of spring barley with the desired quality characteristics, including high grain β-glucan and waxy starch. Results from 2 years of yield trials at Pendleton, Oregon and 1 year at Moro, Oregon suggest that specialty spring barley varieties and advanced lines produce grain yields that are comparable to the grain yields of the most widely grown spring feed barley varieties. The two highest yielding advanced lines produced essentially the same yield as 'Camas' or 'Baronesse'. Grain protein averaged 11.9 and 14.4 percent at Moro and Pendleton, respectively. The test weight of the hull-less lines was similar to wheat test weight grown under the same conditions. There was a higher average percentage of plump kernels at Pendleton than at Moro. The β-glucan concentration in grain from Pendleton averaged about 5.2 percent with the highest concentration of 7.1 percent.

***Key words*:** food barley, spring barley, winter barley

Introduction

Winter wheat is the predominant crop in the dryland Pacific Northwest (PNW), especially in the low (<12 inch) and intermediate (12-18 inch) rainfall zones that characterize much of the region. Spring wheat is grown on much of the remaining acreage. This great dependence on one crop has several adverse consequences, including:

- Increasing grower exposure to economic risk due to wheat price fluctuations
- Increasing the potential for widespread pest problems including weeds, diseases, nematodes, and insects
- Reducing grower flexibility when designing farm management plans

Growers and researchers alike have sought to develop other crops in these agronomic zones. There are several key conditions that a potential alternative crop must fulfill to be viable. First, the crop must be agronomically suited to the winter rainfall pattern that exists in the dryland PNW; about 75 percent of the annual precipitation occurs between October 1 and May 1. Ideally, a new crop will have ready markets, available risk reduction financial products, appropriate technical support information, and be easily planted, managed, harvested, stored, and shipped using current technology. Annual station reports from the Sherman Station near Moro, Oregon from as early as 1916 included reports on the agronomic adaptation and yield of crops such as field peas, Sudan grass, sorghum, field beans, rape, and kale (Stephens 1916). Station reports in the 1920's and 30's included reports on suitability of growing corn and potatoes, among other crops (Stephens and Mitchell 1925, Stephens and Oveson 1935). None of these crops are now grown commercially because they failed to thrive under the winter precipitation patterns, were not economically competitive with winter wheat, or both.

Winter and spring barley are potential alternative crops for much of the low and intermediate rainfall areas where fallow is practiced to minimize the potential for barley to contaminate wheat. Feed barley prices were stagnant or declining throughout the region in recent years but prices have risen dramatically in the last half of 2006 and early 2007 in response to the run-up in wheat and corn prices. Winter malting barley lines are under development but due to the prolonged approval process and demanding quality specifications, it will be some time before these varieties are available.

There is increasing interest in "functional foods" that have specific characteristics that are desired by consumers for their added health, nutrition or other benefits. The FDA approval in 2005, permitting a "heart healthy" claim for barley because the β-glucan in barley has been shown to lower cholesterol (Behall et al. 2004) will increase demand for barley as a food crop. In addition, barley can be used as a feed stock for starch-based ethanol production.

Increasing use of barley fits into two complementary niches - winter barley as an alternative to winter wheat and spring barley after winter wheat to increase cropping intensity (2 crops in 3 years) with a concomitant reduction in wind and water erosion. Winter barley offers agronomic advantages when compared to winter wheat, including greater tolerance to certain diseases (Schillinger et al. 1999), reduction in Rhizoctonia bare patch in wheat (Schillinger and Paulitz 2005), greater drought tolerance (Hayes et al. 2003) and greater salt tolerance (Ludwick 2002). For these reasons, barley is often grown on less desirable sites than wheat. Yields of winter barley at Pendleton have exceeded 6,000 lbs/acre following fallow (Petrie et al. 2003); spring barley yields are lower but often exceed 3,000 lbs/acre following winter wheat.

Grower and researcher experiences indicate that winter barley yields are about 50 percent greater, on average, than spring barley in the winter rainfall region of the PNW; the average yield of fall-seeded barley in our preliminary trial was about 40 percent greater than the same varieties in the spring-seeded trial.

The objectives of this research program are to identify well adapted varieties or lines of spring barley with the desired quality characteristics, including high grain β-glucan and waxy starch, and to develop adapted winter lines with the appropriate quality characteristics. This report will emphasize our work on the first objective.

Materials and Methods

2004-2005 Fall seeding

We seeded seven lines of specialty spring barley along with 'Strider', a well adapted winter feed barley, on October 18, 2004 at the Pendleton Station using a five-row Hege plot drill with 12-inch spacing between rows. The field had been fallow in the 2003-2004 cropping year. All varieties were seeded at 20 seeds/ft^2. Individual plots were 5 by 20 ft and the varieties were arranged in a randomized complete block design with four replications. Fertilizer was applied based on soil test results and weeds were controlled by herbicides. Heading date was noted and plant height was measured at harvest and lodging estimated. The trial was harvested on July 12, 2005 using a Wintersteiger plot combine. Grain was weighed to estimate yield and test weight was measured after de-awning and grain protein was measured by the Oregon State University (OSU) Cereal Quality Laboratory. The data were analyzed using ANOVA and the LSD, if appropriate, was calculated at the $P < 0.05$ level.

2005 Spring seeding

The same varieties were also seeded in the spring on March 10, 2005 using the same equipment, seeding rate, and agronomic practices as in the fall seeding, except that heading date and plant height were not recorded.

The 2004-2005 crop year was quite dry and precipitation during the period from September 1, 2004 to August 31, 2005 was only 12.1 inches, or 75 percent of normal. Fall and winter precipitation (September 1 to February 28) was only 55 percent of normal while spring and early summer precipitation (March 1 to July 31) was 8 percent greater than normal.

2006

A total of 33 varieties and advanced lines of waxy, high β-glucan spring barley, both hulled and hull-less were collected from breeders at the USDA-Agricultural Research Service (ARS) at Aberdeen, Idaho; Washington State University; University of Idaho and WestBred, LLC. The characteristics of these lines are shown in Table 1. These varieties were seeded at Pendleton and Moro using a Hege plot drill at 22 seeds/ft^2 on March 14 and 15, 2006, respectively. We seeded 'Baronesse' and 'Camas' spring barley as check varieties. Individual plots were 5 by 20 ft and the varieties and advanced lines were arranged in a randomized complete block design with four replications. Fertilizer was applied as needed based on soil test results and weeds were controlled by using the appropriate herbicides. Plant height was measured prior to harvesting using a Wintersteiger plot combine. Grain was weighed to estimate yield and we measured grain protein, test weight and percent plump kernels.

Table 1. Characteristics of the 33 lines of spring barley grown at Pendleton and Moro, Oregon, 2006.

Line	Hull type	Starch type	β-glucan content
University of Idaho			
Camas	Hulled	Normal	--
Washington State University			
01WA-10001.4	Hull-less	Waxy	--
01WA-12501.2	Hull-less	Waxy	--
01WA-13860.10	Hull-less	Waxy	--
01WA-13860-4	Hull-less	Waxy	--
01WA-13860-5	Hull-less	Waxy	--
02WA-7037.10	Hull-less	Waxy	--
02WA-7037.25	Hull-less	Waxy	--
02WA-7037.9	Hull-less	Normal	--
WA 9892-99	Hull-less	Waxy	--
WestBred, LLC			
Salute (BZ 598-095)	Hulled	Waxy	High
YU 599-006	Hulled	Waxy	High
BZ 502-563	Hulled	Waxy	--
Meresse-2	Hull-less	Waxy	--
YU 501-039 (HB 813)	Hull-less	Waxy	--
BZ 598-161 (HB 811)	Hull-less	Waxy	--
Baronesse	Hulled	Normal	--
USDA-ARS Aberdeen, ID			
03AH1170	--	Waxy	--
03AH2214	--	Waxy	--
03AH2215	--	Waxy	--
03AH2229	--	Waxy	--
03AH2616	--	Waxy	--
03AH2651	--	Waxy	--
03AH2689	--	Waxy	--
03AH2854	--	Waxy	--
03AH2873	--	Waxy	--
03AH3052	--	Waxy	--
03AH3054	--	Waxy	--
03AH3058	--	Waxy	--
03AH3483	--	Waxy	--
03AH3491	--	Waxy	--
03AH6481	--	Waxy	--
03AH6482	--	Waxy	--

Results and Discussion

2004-2005 Growing season – fall seeding

Seedling emergence was excellent for 'Strider', a well adapted winter feed barley, but all specialty spring barley lines exhibited reduced emergence compared to 'Strider'. 'Waxbar' had about 50 percent stand reduction observed on April 6, 2005 while 'Merlin' had about 25 percent stand reduction. The other lines exhibited 5 to 20 percent stand reductions. This stand reduction appeared to be related to poor emergence; there was little or no winter kill because the winter was relatively warm with very little snow. The reason for this poor emergence and stand establishment is not clear. 'Waxbar' and 'Merlin' were also much slower to begin active growth in the spring compared to the other specialty lines or to 'Strider'.

All varieties headed within 6 days of each other; 'Azhul' headed first on May 11 and 'Waxbar' headed last on May 17. Plant height varied from 'Merlin' at 26 inches to 'Waxbar' at 41 inches tall at harvest. 'Strider', 'Azhul', 'Fibar', 'Waxbar' and 'CDC Alamo' exhibited lodging at harvest. 'Strider' had more than twice the lodging of 'CDC Alamo', the specialty line with the greatest lodging.

'CDC Alamo' and 'CDC McGwire' produced the greatest yields among the specialty barley lines with 4,215 and 4,145 lbs of grain/acre, respectively. In comparison, 'Strider' feed type barley produced 4,845 lbs of grain/acre. Lodging appeared to have little impact on grain yield as 'Strider' had the most lodging and the greatest yield overall, while 'CDC Alamo' had the greatest yield and most lodging among the specialty barley lines we grew.

2005 Growing season – spring seeding

There was no lodging in the spring-seeded trial and plant height was comparable to the height of fall-seeded barley. 'Waxbar' and 'Merlin' had poor emergence and stand establishment in the spring seeding, suggesting that the cause of the poor emergence could be related to seed quality.

Spring seeding resulted in lower yields for seven of eight varieties compared to fall seeding; only 01AH 2812 produced less grain in the fall seeding (Table 2). The overall average grain yield was about 40 percent greater for fall seeding compared to spring seeding. 'CDC Alamo' did well in both fall and spring seeding; it was the highest yielding hull-less line in the fall seeding and second highest yielding in the spring seeding. Other varieties tended be ranked about the same in fall and spring seeding, except for 01AH 2812, which was the highest yielding variety in the spring seeding but next to the lowest yielding in the fall seeding. 01AH 2812 had a slightly lower yield when seeded in the fall compared to the spring. 'Strider' produced the most grain when seeded in the fall but was the sixth ranked variety when seeded in the spring. 'Baronesse', a high-yielding spring feed barley, produced the greatest grain yield at 4,510 lbs/acre. This was an exceptionally high yield given the unusual weather; the yield differential in this trial may not accurately reflect the yield differences under more normal rainfall conditions. This trial was established in a field that was fallow in the 2003-2004 growing season and most spring barley is seeded after a winter cereal.

The highest yielding hull-less lines, 'CDC Alamo' and 'CDC McGwire', produced about 86 percent of the yield of 'Strider' when seeded in the fall. These results compare favorably with results from the trials in the Treasure Valley where spring types have yielded quite well when fall-seeded and not subjected to winterkill. However, we do not recommend planting these spring-type barley varieties in the fall in northeastern Oregon where it is likely that unacceptable winter injury would occur in many years.

Table 2. Variety and agronomic characteristics of winter- and spring-seeded barley lines at Pendleton, Oregon, 2004-2005.

Variety	Growth habit*	Spike type	Hull	Way	Fall seeding				Spring seeding
					Plant ht	Lodging	Heading date	Yield	Yield
					- in -	-- % --		----- lb/acre	-----
Strider	w	6	+	-	40	36	5/12	4,845	2,255
01AH2812	s	2	-	+	35	0	5/12	3,035	3,145
Azhul	s	6	-	+	32	4	5/11	3,760	3,005
CDC Alamo	s	2	-	+	37	14	5/14	4,215	3,080
CDC Fibar	s	2	-	+	40	8	5/15	3,605	2,825
CDC McGwire	s	2	-	+	36	0	5/14	4,145	2,530
Merlin	s	2	-	+	26	0	5/15	3,895	2,530
Waxbar	s	2	-	+	41	13	5/17	2,765	1,535
Baronesse	s	2	+	-	--	--	--	--	4,510
$LSD_{(0.05)}$					1.9			470	490

* s = spring habit; w = winter habit.

2006 Moro

Growing conditions were favorable for spring-seeded barley in 2006 at both Moro and Pendleton. Total precipitation during the crop year (September 1 to August 31) was 18.9 inches at Pendleton and 16.9 inches at Moro. These figures are 15 and 49 percent greater than the long-term average at Pendleton and Moro, respectively. The distribution of rainfall was especially favorable as April, May, and June precipitation was 45 and 115 percent greater than normal at Pendleton and Moro, respectively.

The greatest grain yield at Moro was slightly more than 4,000 lbs/acre; 'Camas' and two advanced lines (BZ-502-563 and 02WA-7037.25) produced more than 4,000 lbs of grain/acre in 2006 while 'Baronesse', the most widely planted variety of spring barley, produced 3,895 lbs of grain/acre (Table 3). Grain protein ranged from 9.6 percent for 'Camas' to 13.5 percent for a Washington line (01WA-13860-10) and averaged 12.9 percent. Test weight ranged from 49 lbs/bu to 62 lbs/bu. Fifteen lines had test weights of 60 lbs/bu or greater. The hulled varieties and lines had lower test weight values than the hull-less varieties. Plump kernels were taken to be kernels that did not pass through a screen with 6/64 inch openings. The plump kernels ranged from a low of 18 percent (three lines) to a high of 74 percent plump kernels from the advanced line 03AH2229; unfortunately, 03AH2229 was a low yielding variety at both Moro and Pendleton. There was an average of 39 percent plump kernels at Moro.

Table 3. Spring barley grain yield, protein, test weight, and percent of plump kernels and β-glucan at Moro, Oregon, 2006.

Variety	Grain yield	Protein	Test wt	Plump	β-glucan
	lb/acre	--%--	lb/bu	% on 6/64	% (w/w)
BZ-502-563	4,160	12.3	54	47	5.0
Camas	4,045	9.6	55	59	3.2
02WA-7037.25	4,015	10.7	56	34	3.4
Salute BZ598-095	3,985	11.5	52	63	5.0
Baronesse	3,895	9.7	51	38	3.4
Yu 501-0039 (HB813)	3,750	12.2	56	28	6.0
03AH2873	3,735	11.9	61	39	4.7
01WA-13860-10	3,645	13.5	59	37	4.6
03AH6482	3,600	11.3	59	57	3.5
02WA-7037.9	3,590	11.4	56	26	3.6
01WA-13860.5	3,570	12.4	59	22	4.6
Meresse-2	3,555	11.8	61	24	5.8
Yu 599-006	3,535	12.5	49	70	5.4
01WA-12501.2	3,485	11.2	60	29	5.5
WA-9820-98	3,470	11.7	59	18	4.0
03AH1170	3,445	12.7	56	30	5.1
03AH6481	3,425	11.5	62	62	4.5
03AH2651	3,355	10.9	60	47	5.2
02WA-7037.10	3,345	10.8	60	35	3.5
03AH3491	3,330	12.2	60	51	6.3
03AH2854	3,320	11.7	58	18	3.9
BZ 598-161(HB811)	3,320	12.9	58	19	4.5
01WA-10001.4	3,295	13.0	60	14	4.0
03AH2689	3,285	12.1	60	54	4.9
01WA-13860.4	3,280	13.5	57	18	5.3
03AH2215	3,160	11.5	58	50	7.0
03AH2214	3,150	11.3	61	62	7.5
03AH3052	3,120	11.4	60	33	6.4
03AH3483	3,075	12.8	60	33	5.4
03AH3054	3,025	13.2	59	30	5.0
03AH2229	2,945	13.2	62	74	5.8
03AH3058	2,945	12.8	60	37	5.6
03AH2616	2,935	12.2	61	27	5.9
Average	3,450	11.9	58	39	5.3
LSD (0.05)	480	2.0	3.84	20.50	1.7
CV %	10	8.1	5.4	42.5	16.6

2006 Pendleton

The favorable growing conditions in the spring of 2006 are reflected in the yields recorded at Pendleton. Three varieties (BZ-502-563, 'Camas' and 'Salute BZ-598-095') produced more than 5,000 lbs of grain/acre while 'Baronesse' was close behind at 4,980 lbs of grain/acre (Table 4). BZ-502-563 and 'Camas' produced the first and second greatest yields at both Moro and Pendleton, and four of the top five producing varieties were the same at Moro and Pendleton.

Grain protein values were higher at Pendleton, where the average grain protein was 14.4 percent compared to 11.9 percent at Moro. Grain protein at Pendleton ranged from 12.3 percent for 'Salute BZ-598-095' up to 16.9 percent for a Washington line (01WA-13860-5).

Test weight ranged from 53 lbs/bu up to 61 lbs/bu. Twenty-one lines had test weights of 60 lbs/bu or greater. The hulled varieties and lines had lower test weight values than the hull-less varieties; the test weight of the hull-less lines was similar to the typical values for test weight of spring wheat grown in Pendleton.

The plump kernels ranged from a low of 16 percent to a high of 87 percent from the advanced line 'Salute BZ-598-095'. The average of 58 percent plump kernels at Pendleton compared to only 39 percent at Moro.

High β-glucan concentration is a desired trait for the potential food uses for barley because the β-glucan is the source of the health benefits. 'Camas' and 'Baronesse' had the lowest β-glucan concentration at 3.29 and 3.47 percent, respectively; the β-glucan concentration in the other lines ranged as high as 7.13 percent in 03AH2214.

Table 4. Spring barley grain yield, protein, test weight, and percent of plump kernels and β-glucan at Pendleton, Oregon, 2006.

Variety	Grain yield	Protein	Test wt	Plump	β-glucan
	lb/acre	--%--	lb/bu	% on 6/64	% (w/w)
BZ-502-563	5,180	12.9	53	78	5.3
Camas	5,085	13.0	55	64	3.4
Salute BZ-598-095	5,070	12.3	55	87	5.4
Baronesse	4,980	13.0	53	66	3.5
03AH6482	4,760	13.9	61	70	5.5
03AH6481	4,690	14.5	60	64	5.6
01WA-13860.5	4,675	16.9	60	53	4.7
02WA-7037.9	4,565	14.3	57	42	3.7
01WA-12501.2	4,560	14.9	60	64	6.0
03AH2873	4,555	14.5	61	60	5.8
03AH2854	4,500	14.3	60	47	4.1
03AH2689	4,480	14.0	60	59	6.4
Yu 501-0039 (HB813)	4,465	13.8	59	61	4.8
01WA-10001.4	4,450	14.5	60	39	5.0
01WA-13860-10	4,425	14.3	60	73	5.4
03AH2616	4,415	15.1	60	46	6.4
03AH3491	4,345	14.3	60	61	6.0
BZ 598-161(HB811)	4,330	14.0	60	53	4.5
03AH2651	4,295	14.6	60	65	5.8
02WA-7037.10	4,250	14.4	59	51	4.0
02WA-7037.25	4,240	14.3	57	50	4.0
01WA-13860.4	4,240	15.4	59	41	5.4
Meresse-2	4,220	14.8	61	49	5.7
03AH2214	4,170	15.2	60	71	6.8
Yu 599-006	4,155	13.4	51	83	6.7
03AH2215	4,150	15.5	60	60	6.3
03AH3483	4,040	14.7	60	54	5.5
03AH3054	4,025	15.0	60	47	6.7
03AH1170	4,025	13.6	59	59	4.6
03AH3058	3,995	14.8	60	53	6.8
WA-9820-98	3,970	14.3	57	16	3.7
03AH3052	3,965	14.6	60	45	6.3
03AH2229	3,790	15.7	61	71	6.6
Average	4,395	14.4	59	58	5.3
LSD (0.05)	490	1.1	2.93	*	0.9
CV %	8.0	3.9	4.5	24.5	8.6

Summary

Results from 2 years of yield trials at Pendleton and 1 year at Moro suggest that specialty spring barley varieties and advanced lines produce grain yields that are comparable to the grain yields of 'Baronesse' and 'Camas', two widely grown spring feed barley varieties. The two highest yielding advanced lines produced essentially the same yield as 'Camas' or 'Baronesse'. Grain protein averaged 11.9 and 14.4 percent at Moro and Pendleton, respectively. The test weight of the hull-less lines was similar to wheat test weight grown under the same conditions. There was a higher average percentage of plump kernels at Pendleton than Moro, which would be expected based on the higher rainfall at Pendleton. The β-glucan concentration in grain from Pendleton averaged about 5.2 percent with the highest concentration of 7.1 percent.

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Effect of Swathing, "Pushing," or Direct Cutting on Yield and Oil Content of Dryland Winter Canola and Spring Rapeseed in Eastern Oregon

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Abstract

Canola or rapeseed is susceptible to pre-harvest shatter because of differential maturing or windy conditions. We compared forced lodging ("pushing"), swathing, and direct combining of winter canola and spring rapeseed. Force lodging is harvest method that is becoming accepted practice in the region. The crop canopy is forced lodged in a uniform direction. This allows to crop to mature in a prone position. We constructed a 5-foot wide header attached to a narrow-base skid steer swather to conduct forced lodging. In 2005 we conducted a harvest experiment on winter canola in 2005 and spring rapeseed in 2006. Winter canola or spring rapeseed was either force lodged at first brown seed and 1/3 brown seed, swath at 1/3 brown seed and 2/3 brown seed, or direct combined as a standing crop at maturity. We compared yield and oil content of these harvest methods. Winter canola yields were similar for forced lodging and swathing, but were significantly lower when direct combined. Although swathing had similar yield it is slower and more costly than forced lodging. Harvest results of spring rapeseed show that direct combining produced the highest yields with forced lodging and swathing have lower yields. This may be due to canopy height or genetic differences. Harvest method had no effect on oil content.

Introduction

Timing and method of harvest of canola is critical for optimum grain yield and quality. Canola must be harvested as soon as the crop matures to avoid shatter loss. Unfortunately, many fields in the Pacific Northwest (PNW) are quite variable in slope, elevation, and soil depth (Douglas et al. 1990). Consequently, crop maturity is seldom uniform. At harvest, canola fields typically have a mix of immature and mature areas, which leads to harvest problems. Some plants show pod shattering, while others are too green to harvest. Waiting for "dry down" to direct combine canola can be costly, if preharvest winds shatter the seed pods. We have observed preharvest shatter losses from a 4-hour-long, 20 mph wind to be as high as 30 percent of a 2,000 lb/acre yield. Also, direct combining of canola can be very slow. To reduce preharvest shatter, hasten maturity, reduce wind exposure, and increase harvest speed, swathing the crop is sometimes the preferred method of harvest. Swathing prior to full maturity reduces the potential for pod shatter and helps hasten maturity, but adds about $25/acre in costs and can result in reduced oil content and inferior oil quality if done too early. While this practice lowers shatter risk and improves speed of harvest, it does not completely solve the problem of differential maturity. The recommended crop stage for swathing is one-third brown seed. At this growth stage, there is sufficient photosynthate in the plant to carry seed to maturity. However, growers must compromise on this condition. Parts of a field will be less that one-third brown seed and some will be more. If seed is too green, (less than one-tenth brown seed) yield can be reduced by 10 percent and quality reduced from immature seed at harvest (Wysocki et al. 1996). If seed is too ripe (more than two-thirds brown seed) seed can be lost by shatter from mechanical agitation at swathing. The duration from first brown seed to two-thirds brown seed is narrow, usually 8-10 days. Canola fields can have areas that differ in maturity by more that this interval, so portions of the field are often swathed outside the optimum window. Recently, another harvesting method, known as "pushing" or forced lodging, has been used in the region. A tractor-mounted shield header is used to "push" the canopy over, essentially lodging the crop all in one direction. One such implement is the "yield shield" manufactured by Ag Shield Manufacturing (Benito, Manitoba, Canada) (Fig. 1). Plant stems are bent at 4-6 inches from the soil surface, forcing the plant to lie prostrate. The plants mature in a lodged position, with the stems attached. Pushing canola down reduces shatter risk, but also allows plant to mature naturally. Canadian research has shown mixed results depending on environmental conditions. When the crop was subject to wind shatter, swathing or pushing was superior to direct harvest. In absence of wind, direct harvest was superior, particularly when the crop naturally lodges.

To get a better understanding of the influence of harvest methods on yield and oil content, we conducted experiments on swathing, pushing, and direct cutting of canola in the 2004-2005 and 2005-2006 growing seasons. Our objectives were to compare yield and oil content of winter canola harvested by these three methods, at two crop stages. Pushing was done at first brown seed and one-third brown seed on the main branch or raceme. Swathing was done at one-third and two-thirds brown seed on the main raceme, and direct harvest was done at full brown seed and less than 10 percent seed moisture content.

Methods

Conducting replicated field trials of pushing, swathing, and direct combining required a plot machine to force lodge or "push" canola. We constructed a plot "pusher" by welding together a divider-pusher header (Fig. 1a) and mounting it to a John Deere 880 skid steer swather (Fig. 2b). This header worked well for "pushing" (forced lodging) canola. To our knowledge this is the first plot canola "pusher" constructed for experimental purposes.

During the 2004-2005 growing season a uniform area in a field of commercial winter canola near Pendleton, Oregon was selected for study. Winter canola (cv. 'Olsen') in the field was planted into chemical fallow on 30 August 2004 using a Great Plains NT drill with 10-inch row spacing. Sowing rate was 5 lb seed/acre. Seventy-five lb nitrogen (N), 15 lb sulfur (S), and 10 lb phosphate (P_2O_5)/acre were applied. The harvest experiment was superimposed onto the field area using a random complete block design with four replications. Treatments consisted of 1) pushing at first brown seed on the main raceme, 2) pushing at one-third brown seed on the main raceme 3) swathing at one-third brown seed on the main raceme, 4) swathing at two-thirds brown seed on the main raceme, and 5) direct combining at fully ripe seed. Individual plot dimensions were 5 by 50 ft. Pushing was done with the experimental plot pusher. Swathing was done with a 5-ft-wide Swift plot swather. Direct combining and combining of push and swath treatments were done with a Hege 140 combine with a 5-ft header, equipped with an auger-feed header and canola sieves. The center 5 ft of 15-ft-wide plots were harvested for the direct combine treatments. This was done to assure a full header and provide an appropriate buffer so as not isolate long thin strips of standing canola prior to combining. Oil content of seed was measured by the University of Idaho using Nuclear Magnetic Resonance spectroscopy. Yields were adjusted to 8 percent seed moisture content.

During the 2005-2006 season, winter canola (cv. ‘Athena’) was sown in a block at Columbia Basin Agricultural Research Center, Pendleton, Oregon. The block was planted into chemical fallow on 2 October using a Great Plains NT drill with 10-inch row spacing. Sowing rate was 6 lb seed/acre. Seventy-five lb N, 15 lb S, and 10 lb P_2O_5 per acre were applied. The stand did not establish uniformly enough to conduct the harvest experiment. Glyphosate was applied in the spring and the block was reseeded to spring rapeseed (cv. ‘Sterling’) on 25 March. The harvest experiment was superimposed onto the block using a random complete block design with eight replications with the same treatments as 2004-2005. Individual plot dimensions were 5 by 120 ft. Direct combined plots were again 15-ft wide with the center 5-feet being the plot area. Yield and oil content were determined in the same manner as the previous year.

Results

Timing, yields, and oil content of the various harvest treatments are listed in Table 1 and are shown graphically in Figure 2. In 2004-2005, “pushing canola” at one-third brown seed produced the best results at 2,232 lb seed/acre. This was followed by “pushing” at first brown seed (2,132 lb/acre), swathing at one-third brown seed (2,075 lb/acre), and swathing at two-thirds brown seed (2,057 lb/acre). Statistically the means of these four treatments were not different. Yield of the direct-harvest treatment was 1,625 lb/acre. This was statistically lower than pushing or swathing. Compared to direct cutting and swathing at one-third brown seed (the recommend stage for swathing), “pushing” at one-third brown seed resulted in an increased harvest yield of 597 lb/acre (26 percent) and 157 lb/acre (7 percent) respectively. Pushing at first brown seed or at one-third brown seed was superior to all swathing treatments or direct harvesting, and swathing treatments performed better than direct harvesting. In 2004-2005, oil content was unaffected by method of harvest (Table 1).

In 2005-2006, direct harvest produced the best results at 1,261 lb seed/acre. The mean of this treatment was statistically higher than the other treatments. This was followed by swathing at one-third brown seed (1,087 lb/acre), “pushing” at first brown seed (1,013 lb/acre), swathing at two-thirds brown seed (968 lb/acre), and “pushing” at one-third brown seed (930 lb/acre). Direct harvesting resulted in increased yields of 14, 20, 23, and 26 percent over swathing at one-third brown seed, “pushing” at first brown seed, swathing at two-thirds brown seed and “pushing” at one-third brown seed, respectively. In 2005-2006, oil content was also unaffected by method of harvest (Table 1).

Discussion

Yield results obtained in 2004-2005 and 2005-2006 are contrasting (Table 1). The results of the two harvest seasons many not be directly comparable because spring rapeseed was used in 2005-2006. Canopy height was substantially less for the spring rapeseed (46 inches) versus winter canola (68 inches). Direct harvesting the much taller winter canola is more difficult and may explain the better performance of swathing and pushing in 2004-2005. Excessively windy conditions did not occur in either year of this study, so wind shatter was not a factor. Crop maturity in the winter canola in 2004-2005 occurred more slowly than in the spring rapeseed in the 2005-2006 season. This may account for the better performance of "pushing" and swathing of winter canola. Those treatments that allow winter canola to ripen more quickly may have an advantage. In a previous study, it was found that swathing too early can have a large negative impact on yield (Wysocki et al. 1996). For this reason we avoided swathing before one-third brown seed.

Conclusion

In this study, harvest of winter canola showed better results when the crop was pushed or swathed. Harvest results for spring rapeseed showed just the opposite. The contrasting result between the two seasons may be due to plant height, cultivar differences, or differences between winter and spring crops. Because of the taller stature, longer ripening period, and slowness of direct harvesting of winter canola, pushing or swathing reduces the risk of shatter loss and hastens harvest. Because pushing is less costly and results in more uniform feeding into the combine than windrows, pushing winter canola is a better option. Brown et al. (1999) found in northern Idaho that swathing spring canola was an advantage only in wet or late years when maturity was delayed. The result in the 2005-2006 harvest of spring rapeseed would suggest this for eastern Oregon as well. More harvest trials are needed to get the better understanding of harvest techniques on fall and spring brassicas. Also measurement of shatter loss should be made to determine the specific reason for higher yields. Oil content does not appear to be affected by affected by harvest method.

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Figure 1. Yield shield "pushing" spring canola.

Figure 2. (A) Plot "pusher header." (B) Header mounted on John Deere 880 swather body.

Table 1. Timing, yield, and oil content of various harvest methods of winter canola and spring rapeseed at Pendleton, Oregon.

2004-2005 (winter canola)			
Treatment	Date of operation	Yield (lb/acre) (LSD 0.05 = 390)	Oil content (%) (LSD 0.05 = 1.6)
Push first brown seed	16 Jun	2,182 A	39.3 A
Push 1/3 brown seed	20 Jun	2,232 A	39.4 A
Swath 1/3 brown seed	20 Jun	2,075 A	39.4 A
Swath 2/3 brown seed	24 Jun	2,057 A	39.5 A
Direct combine (standing crop)	7 Jul	1,635 B	39.5 A
2005-2006 (spring rapeseed)			
Treatment	Date of operation	Yield (lb/acre) (LSD 0.05 = 123)	Oil content (%) (LSD 0.05 = 1.3)
Push first brown seed	20 Jul	1,013 BC	36.1 A
Push 1/3 brown seed	24 Jul	930 C	36.4 A
Swath 1/3 brown seed	24 Jul	1,087 B	36.4 A
Swath 2/3 brown seed	28 Jul	968 BC	36.6 A
Direct combine (standing crop)	1 Aug	1,261 A	36.9 A

*Means followed by the same letter are not statistically different at P = 0.05.

Long-term Experiments at Columbia Basin Agricultural Research Center, Pendleton, Oregon 2006

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Abstract

The Columbia Basin Agricultural Research Center is home to the oldest continuous cropping experiments in the Pacific Northwest. The perennial grassland, conventional-till continuous cereal, and crop residue management experiments were initiated in 1931. The tillage-fertility and wheat-pea rotation were initiated in 1940 and 1963, respectively. In 1998 a no-till continuous cereal trial was added to mirror the conventional-till continuous cereal trial. This article summarizes results obtained in 2006. *Continuous cereal*: in both conventional and no-till cropping systems, spring barley produced significantly higher yields than spring and winter wheat. Winter wheat yields were 17 percent higher under conventional tillage than under no-till. Spring barley and spring wheat monocultures produced grain yields that were not significantly different in tilled and no-till systems. *Crop residue*: yield was highest when manure was applied and intermediate when 40 lb or 80 lb of nitrogen (N) was applied. Nonfertilized treatments, with or without burning of stubble, resulted in the lowest yields. *Wheat-pea rotation*: wheat yields were highest when soil was moldboard or chisel plowed as compared to no-till treatments. Pea yields were highest in the no-till and fall disk treatments, and less in the spring and fall plow treatments. *Tillage fertility*: the tillage fertility experiment was in fallow during 2006. *Continuous no-till winter wheat (USDA):* yields and test weight continue to be collected on this trial with a 9-year average yield of 70.5 bu/acre.

***Key words*:** carbon sequestration, cropping systems, long-term research, organic matter

Introduction

Long-term research guides future agricultural development by identifying the effects of crop rotation, tillage, variety development, fertilizer use, aerial and surface contamination, and organic amendments on soil productivity and other soil properties. Identification and evaluation of many changes often require 10 to 20 years to identify and quantify. Soil microflora and soil-borne plant pathogens require from 2 to 8 years in a new cropping sequence or tillage system to reach a stable equilibrium. Long-term experimentation is required to understand interactions among soil, water, and plant factors for both agronomic and environmental policy decisions. The oldest experiments (Table 1) in the Pacific Northwest (PNW) are at the Columbia Basin Agricultural Research Center (CBARC) near Pendleton, in the intermediate rainfall (16.5 inches mean annual precipitation) zone. A brief description of these experiments and the results obtained in the 2006 crop year are presented in this paper. The treatments have changed over the years and the descriptions below refer to current procedures. Detailed descriptions of the protocols and how they have changed over time have been compiled into a database located on our network server. Most of this information is available on the web at http://oregonstate.edu/~rhinhark/Longterm/. Examples of recent research topics utilizing these long-tem experiments are: earthworm populations as a surrogate for soil quality; water infiltrations and storage; soil structure; nematode population sampling; economics and sustainability; carbon sequestration and carbon cycle modeling; soil organic matter; nitrogen relationships; microclimate and soil temperature relation to plant growth; bulk density effect; and penetrometer resistance.

Description of Experiments

Table 1. Long-term experiments at Columbia Basin Agricultural Research Center, Pendleton, Oregon.

Experiment	Treatments	Year initiated
Perennial grassland	None	1931
Conventional-till continuous cereal	N rate	1931
Residue management	N rates, manure, burning, pea vine	1931
Tillage-fertility	Tillage, N & S rates	1940
Wheat-pea	Tillage, N rates	1963
No-till continuous cereal	N rate	1998
Continuous no-till winter wheat (USDA)	None	1998

Managed Perennial Grassland

The perennial grassland site (150 by 360 ft) contains no experimental variables but has been maintained since 1931. Usually scientists sample the area to obtain data to answer specific questions they are investigating at other sites. The site is intended to approximate a near-virgin grassland and serves as a baseline for evaluating changes in other cropping systems. It is periodically reseeded with introduced grass selections, occasionally fertilized, and infrequently irrigated. The dominant grass species is bluebunch wheatgrass (*Agropyron spicatum* var. 'Secar') with very minor amounts of Idaho fescue (*Festuca idahoensis* var. 'Joseph'). Weeds are controlled as needed, particularly witchgrass (*Panicum capillare*), common mallow (*Malva neglecta*), and downy brome (*Bromus tectorum*). Prickly lettuce (*Lactuca serriala*) and rat-tail fescue (*Vulpia myuro*) appear in areas where the grass stand is thin. As common mallow is controlled, other weeds such as Jim Hill mustard (*Sisymbrium altissimum*), redstem filaree (*Erodium cicutarium*), and henbit (*Lamium amplexicaule*) have appeared. This stand was renovated and reseeded during 2002 and 2003. Broadleaf weeds were controlled in 2003 and 2004 with broadcast applications of dicamba/carfentrazone-ethyl and 2,4-D amine/MCPP mixtures and spot applications of MCPA. In 2005 and 2006, broadleaf weeds were controlled with application of a bromoxynil/MCPA mixture. As broadleaf weeds are almost completely controlled with herbicides, grassy weeds such as downy brome and rat-tail fescue (*Vulpia myuros*) are gaining more importance as weed species in areas where bluebunch wheatgrass stands thin.

This site received limited grazing from 1931 to 1985 but has not been grazed since. Above-ground productivity was measured in 2004, 2005, and 2006. Species counts were initiated in 2004. A 10-year comprehensive soil sampling was completed in 2006 to determine carbon status and other characteristics. Vegetation is sometimes clipped during or after summer growth and the site is currently flail mowed at a 2-inch height in late summer of each year.

During late summer of 2006, bluebunch fescue seed was combine-harvested from the area. This seed was used to reseed areas with thin bluebunch stands and an area where a new sewer line was placed across the southern end of the area. As part of this work the leach field from the old septic system, which had encroached and affected the central portion of this grassland, was decommissioned. The new leach field is located in the field to the west of this area and does not impact the grassland.

Continuous Cereal Experiments

The objectives of the various continuous cereal monocultures have varied over the years; however, the current objective is to determine the effects of annual mono-cropping on crop yield and soil productivity. Annual monoculture plots of winter and spring wheat and spring barley are maintained using moldboard plow (inversion) tillage. In each plot there are fertilized and unfertilized blocks. Treatment histories for the tilled plots are shown in Table 2. A no-till (direct-seeded) annual winter and spring wheat and spring barley companion plot was established in 1998 and the treatments are shown in Table 3. The plots are not replicated. The most practical, generally recommended methods and equipment available to growers are used. In 2006, a John Deere 8300 double-disk drill on 6.8-inch spacing was used to seed all conventional-till monocultures. In 2006, a John Deere 1560 disk drill on 7.5-inch spacing was used to seed all no-till monocultures. Spring barley ('Baronesse'), spring wheat ('Zak'), and winter wheat ('Stephens') plots had seeding rates and stands shown in Table 4.

All fertilized monocultures received the equivalent of 100 lb of 16-20-0-14/acre. In conventional-till spring plots the fertilizer was applied as a plowdown dry product. In conventional-till winter wheat plots the fertilizer was shank applied after plowing. In no-till monocultures the fertilizer was drill applied at seeding as a mixture of ammonium thiosulfate and ammonium polyphosphate solutions. In conventional-till spring plots the balance of the nitrogen (N) (64 lb N/acre) was applied as plowdown urea. In the conventional-till winter wheat monoculture the balance of the N (64 lb N/acre) was shank applied as urea ammonium nitrate solution after plowing. In no-till monocultures the balance of the N (74 lb N/acre for spring sown crops and 84 lb N/acre for fall winter wheat) was drill applied as urea ammonium nitrate solution. Glyphosate was applied to all monocultures before sowing or plowing except for conventional till winter wheat. MCPA ester and metribuzin were used to control broadleaf weeds in the winter wheat no-till monoculture. Bromoxynil and MCPA ester were used to control broadleaf weeds in all other monocultures. Downy brome was controlled in the no-till winter wheat monoculture with a preemergence application of metribuzin. Rat-tail fescue made its first appearance in the no-till spring wheat monoculture and was controlled with preplant glyphosate and hand weeding. No postharvest weed control was required. In late May, cereal leaf beetle (*Oulema melanopus*) infestations reached mild to severe levels in all monocultures with spring wheat monocultures being hardest hit. All cereals on the Pendleton station were treated with malathion during mid-June and cereal leaf beetle was adequately controlled. 'Zak' spring wheat was treated with propiconazol at the time of broadleaf herbicide application to prevent stripe rust (*Puccinia striiformis*) buildup on this susceptible variety. On May 4 the no-till spring barley monoculture displayed the results of a moderate frost. Minimum temperatures on May 2 reached 23°F. The tilled spring barley monoculture did not display the results of this frost event.

Table 2. Treatment history of the tilled continuous cereal monocultures at Columbia Basin Agricultural Research Center, Pendleton, Oregon.

Period	Crop grown	Variables	N application
			lb/acre
1932-1950	Winter wheat	Fertilizer rate and type	0-126
1951-1958	Winter wheat	None	0
1959-1976	Winter wheat	None	70
1977-1992	Winter wheat	None	80
1993-present	Winter wheat	Fertility	0, 80
1932-1953	Spring wheat	Fertilizer rate and type	0-94
1954-1958	Spring wheat	None	0
1959-1976	Spring wheat	None	74
1977-1992	Spring wheat	None	80
1993-present	Spring wheat	Fertility	0, 80
1982-1994	Spring barley	None	80
1994-present	Spring barley	Fertility	0, 80

Table 3. Treatment history of the direct-seeded continuous cereal monocultures at Columbia Basin Agricultural Research Center, Pendleton, Oregon.

Period	Crop grown	Variable	N application
			lb/acre
1998-present	Spring barley	N rate	0, 90
1998-present	Spring wheat	N rate	0, 90
1998-present	Winter wheat	N rate	0, 100

Table 4. Target seeding rates and stand for fertilized continuous cereal monocultures in 2006 at Columbia Basin Agricultural Research Center, Pendleton, Oregon.

Crop grown	System	Target seeding rate	Stand
		seeds/ft^2	plants/ft^2
Winter wheat	Conventional till	22	17
Winter wheat	No-till	25	15
Spring barley	Conventional till	23	20
Spring barley	No-till	26	18
Spring wheat	Conventional till	26	22
Spring wheat	No-till	29	20

Crop Residue Management Experiment

The crop residue experiment is the most comprehensive of the long-term experiments at Pendleton. The objective of this experiment is to determine the effects of N application, burning, and pea vine and manure application on soil properties and productivity in a conventional moldboard plow, winter wheat-summer fallow production system. Treatments and treatment history are shown in Table 5. The experimental design is an ordered block consisting of 9 treatments (10 originally) and 2 replications. The experiment contains duplicate sets of treatments that are offset by 1 year so that data can be obtained annually. In the fall of 2005 plots were seeded to 'Stephens' using a John Deere 8300 double-disk drill on 6.8-inch spacing. The target sowing rate was 22 seeds/ft^2.

Glyphosate was applied before plowing in the spring of 2005. Broadleaf weeds were controlled with bromoxynil and MCPA ester in the spring of 2006. Nitrogen treatments were shank applied as urea ammonium nitrate solution before sowing.

Tillage Fertility Experiment

The objective of the tillage fertility experiment is to determine the effects of three tillage regimes and six N rates on soil properties and productivity in a tilled winter wheat-summer fallow production system. Treatments are shown in Table 6. The experimental design is a randomized block split-plot, with three replications. Main plots consist of three primary tillage systems (moldboard plow, offset disk, and subsurface sweep) and subplots of six N fertilizer rates. These plots were treated with glyphosate in the spring of 2005 before primary tillage occurred. Broadleaf weeds and downy brome are controlled with MCPA ester and metribuzin. Downy brome control is effective except on sweep-plow treatments. In the fall of 2006, plots were seeded to 'Stephens' wheat using a John Deere 8300 double-disk drill on 6.8-inch spacing. The target sowing rate was 22 seeds/ft^2. Nitrogen treatments were shank applied as urea ammonium nitrate solution before sowing. These plots were in fallow during 2006.

Table 5. Treatment history of the crop residue management experiment at Columbia Basin Agricultural Research Center, Pendleton, Oregon.

		1931-1966		1967-1978		1979 to present	
Trt no.	Organic-N addition	RT[1]	N[2]	RT	N	RT	N
			lb/acre		lb/acre		lb/acre
1	---[3]	--	--	--	--	--	--
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]Residue treatment: FD = fall disk, SD = spring disk, NB = no burn, FB = fall burn, SB = spring burn.
[2]Nitrogen rate (lb/acre/crop); applied early October of crop year.
[3]1 ton/acre/crop field weight alfalfa hay applied to plot 11 1939-1949 1-3 days prior to plowing.
[4]Manure treatment: 10 tons/acre/crop wet wt; 47.5 percent dry matter; 1,404 lb Carbon and 113 lb Nitrogen/acre/crop; applied in April or May of plow year (1-3 days prior to plowing).
[5]Pea vines treatment: 1 ton/acre/crop field weight; 88.4 percent dry matter; 733 lb Carbon and 34 lb Nitrogen/acre/crop; applied 1-3 days prior to plowing.

Table 6. Treatment history of the tillage-fertility experiment at Columbia Basin Agricultural Research Center, Pendleton, Oregon.

Primary treatment (tillage)		Tillage depth	Average residue cover at seeding[1]
Symbol	Type		
		inches	%
MP	Moldboard plow	9	37a
DI	Offset disk	6	92b
SW	Subsurface sweep	6	89b

Subtreatment (fertility)		N rate[2]			
No.	Sulfur application history	1941-1952	1953-1962	1963-1988	1989-present
		lb/acre/crop	lb/ acre/crop	lb/acre/crop	lb/acre/crop
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

[1]Means with the same letters are not significantly different at the 0.05 probability level.
[2]Nitrogen applied 7-14 days prior to seeding as ammonium sulfate from 1941 to 1962, ammonium nitrate from 1963 to 1988, and urea-ammonium nitrate since 1989. N was broadcast from 1941 to 1988, and banded 6 inches deep with 12-inch row spacing since 1989.

Wheat/Pea Rotation

The wheat/pea experiment was established in 1963. The objective of the experiment is to determine effects of four tillage regimes on soil properties and productivity in a wheat/legume annual crop rotation. Treatments are shown in Table 7. Crop rotation is winter wheat/dry spring pea and the experimental design is a randomized block with four replications. Each replication contains eight plots (four treatments duplicated within each crop species). Duplicate treatments, offset by 1 year, permit yearly data collection for both wheat and peas. For crop year 2006, all tilled plots were seeded using a John Deere 8300 double-disk drill on 6.8-inch spacing. For crop year 2006, all no-till plots were sown with a John Deere 1560 drill on 7.5-inch spacing. Target sowing rates were 22 seeds/ft^2 for conventional-till winter wheat, 25 seeds/ft^2 for no-till winter wheat, and 8 seeds/ft^2 for spring pea. 'Stephens' winter wheat and 'Universal' dry yellow pea were sown in 2006. All fertilizer was applied as preplant shank-applied liquid fertilizer. Tilled winter wheat plots received 80 lb N/acre while no-till winter wheat plots received 90 lb N/acre. All pea plots received 16 lb N/acre. Both peas and wheat received phosphorus (P) and sulfur (S) along with the N application. Glyphosate was applied to no-till wheat before sowing. Downy brome was not completely controlled in the no-till wheat plots with spring postemergence applications of metribuzin coupled with an MCPA-ester treatment to control broadleaf weeds. Conventional-till wheat plots had a spring application of bromoxynil and MCPA to control broadleaf weeds. Peas received a postplant incorporated application of metribuzin and imazethapyr for broadleaf control. In 2006, pea leaf weevil (*Sitona lineate*) infested peas at the 3- to 4-node stage but damaging populations did not develop and no weevils were detected after the fifth node developed.

Table 7. Current treatments of the wheat/pea experiment at Columbia Basin Agricultural Research Center, Pendleton, Oregon.

Treatment		Primary tillage	
No.	Identification	Wheat stubble	Pea vines
1	Max till	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

Continuous No-till Winter Wheat (USDA)

These plots were established as no-till in the fall of 1997. Prior to that year the plots were planted to conventionally tilled (moldboard plow) winter wheat each fall since 1931. 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 preseeding application of glyphosate was made each fall. The ConservaPak drill was used to seed ‘Stephens’ winter wheat in mid-to-late October at a target rate of 25 seeds/ft^2 or approximately 100 lb/acre. At seeding, the ConservaPak delivers all fertilizer down the fertilizer shank below and to the side of the seed at rates of 105 lb/acre of 16-20-0-14 S and 185 lb/acre of 46-0-0. A broadleaf herbicide application is made in the spring using dicamba and bromoxynil/MCPA plus 2,4-D. Standing stubble is flailed after harvest.

Efforts continue to control downy brome including a sulfosulfuron application in March 1999. Triallate was incorporated at seeding in October 2001. A Clearfield® wheat variety was planted in October 2002, with imazamox applied in March 2003. Sulfosulfuron was again applied in March 2005. In March of 2006 propoxycarbazone-sodium and mesosulfuron-methyl, plus metribuzin was used. Cheatgrass is no longer a major problem. Hand weeding of goatgrass (*Aegilops cylindrica*) has been effective.

Results and Discussion

Precipitation and Temperature

Fallow year 2005 of the 2006 crop year was abnormally dry. Only 73 percent of normal precipitation occurred during the fallow period in 2005. Although September, November, and February of crop year 2006 had below-normal precipitation, total winter season precipitation (September 1, 2005 to February 28, 2006) was normal. The spring season precipitation in 2006 was, however, 152 percent of normal, leading total crop season precipitation (September 1, 2005 to June 30, 2006) to be 120 percent of normal. Based on growing degree days, the crop-year (September 1, 2005 to June 30, 2006), winter (September 1, 2005 to February 28, 2006), and spring (March 1, 2006 to June 30, 2006) temperatures were slightly warmer than the 77-year average (Table 8). Growing degree day accumulations for crop year 2006 were only slightly above the 77-year average. January 2006 was much warmer than normal. Both September and December of 2006 were cooler than normal. Other months displayed close to normal temperature profiles. Damaging frosts were noted from May 2 through May 4, 2006 when minimum temperatures ranged from 23 to 25°F. Spring sowing in 2006 was delayed by abundant precipitation.

Table 8. Precipitation and growing degree days (GDD) in the 2005-2006 crop-year compared to the 77-year average at Columbia Basin Agricultural Research Center, Pendleton, Oregon.

	2006	77-year
Fallow year precipitation (in)	12.0 (2005)	16.5
Crop-year precipitation (in) September 1-June 30	18.8 (2006)	15.7
Two-year precipitation (in)	30.8 (2005-2006)	32.2
Winter season precipitation (in) September 1-February 28	9.7	9.7
Spring season precipitation (in) March 1-June 30	9.1	6.0
Crop-year GDD September 1-June 30	2,709	2,623
Winter season GDD September 1-February 28	1,284	1,228
Spring season GDD March 1-June 30	1,425	1,395

Managed Perennial Grassland

Above-ground biomass was measured in 2004, 2005, and 2006 (Figs. 1 and 2). Areas where biomass was high in 2004 had lower biomass in 2005. Areas with low biomass in 2004 showed increasing biomass in 2005. High biomass areas in 2004 left a thick layer of grass residue on the surface that suppressed plant growth in the spring of 2005. The entire area was flail mowed in late summer of 2005 and 2006 to improve the bluebunch wheatgrass stands. All areas had higher biomass in crop year 2006 due to abundant rainfall in spring of 2006. Species counts were done in the spring of 2004, 2005, and 2006. Compared to 2004, stands of bluebunch wheatgrass were reduced in late spring of 2005 and replaced by areas of weeds or bare ground. Observations in the early spring of 2006 indicated that after flail mowing, the bluebunch wheatgrass stand had recovered. After species and biomass counts in June of 2006, it was observed that bare patches in the spring of 2005 were now infested with downy brome and rat-tail fescue. Herbicides effectively controlled broadleaf weeds in the area.

In the late summer of 2006, bluebunch wheatgrass seed was combine-harvested from the entire area. This seed was used in February 2007 to reseed areas where the bluebunch wheatgrass was thin on the north and south ends of the area. It was also used to reseed an area on the south end where a new septic line was installed across the area.

Continuous Cereal Experiments

Plant stand

In both conventional and no-till winter wheat plots, plant stands in the fertilized portion of each monoculture were not significantly different from stands of the unfertilized portion. Stands of tilled and no-till spring wheat and spring barley and winter wheat monocultures also were not significantly different (Tables 9 and 10). Final stands ranged from 60 percent of targeted rate in no-till winter wheat to 87 percent of targeted rate in tilled spring barley. In general, precipitation and temperatures were adequate in the fall of 2005 and the spring of 2006 to achieve adequate stands under most conditions. Wet conditions in late March led to less than optimum sowing conditions.

Data analysis

Statistical methods suitable for analyzing unreplicated experiments were used to analyze data (Perrett 2006). The data were analyzed as a split-plot design. The whole plot was a strip of field assigned to 1 of 14 treatments. The blocking factor for the whole plot is the field. Each whole plot is divided up into four subplots. Because only one block (or field) was observed, we have no measure of what will happen on fields that are very dissimilar from this field. Therefore the results can only be generalized to fields with similar characteristics to this field. The whole plot was analyzed as an unreplicated randomized complete block design (RCBD) with subsampling.

Grain yield, yield components, and other measurements

Bundle grain yields (Table 9) were correlated to combine grain yields ($r = 0.68$, $P < 0.01$). For brevity, only the analysis of combine grain yield will be shown (Table 10). In 2006, downy brome did not affect yield in any of the winter-sown monocultures (Table 9). Tarweed (*Madia sp.*) was present but did not reduce yield in the no-till winter wheat monoculture (data not presented). Other variables measured were test weight, kernel weight, harvest index, heads/ft^2, spikelets/head, kernels/head, and grain protein.

Fertility effects

Fertilized spring barley, winter wheat, and spring wheat plots produced significantly higher grain yields than unfertilized plots in both tilled and no-till systems (Tables 9 and 10). Fertilization reduced test weights and 1,000-kernel weights in all untilled monocultures and in the tilled spring wheat monoculture. This was significant only in the tilled spring wheat. The number of heads/ft^2 was significantly increased by fertilization in all but the tilled winter wheat. Excluding the tilled winter wheat, the number of heads/ft^2 in unfertilized monocultures was about 62 percent of the

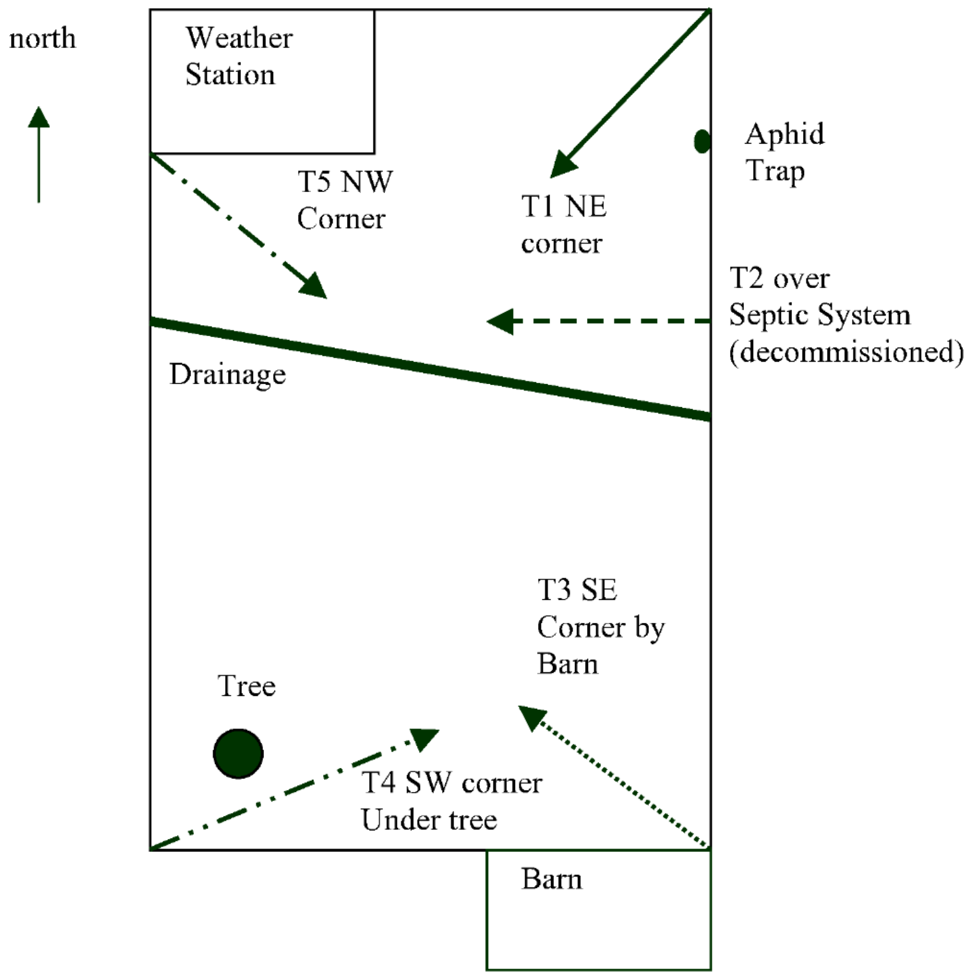

Figure 1. Transects in the long-term perennial grassland at Columbia Basin Agricultural Research Center, Pendleton, Oregon.

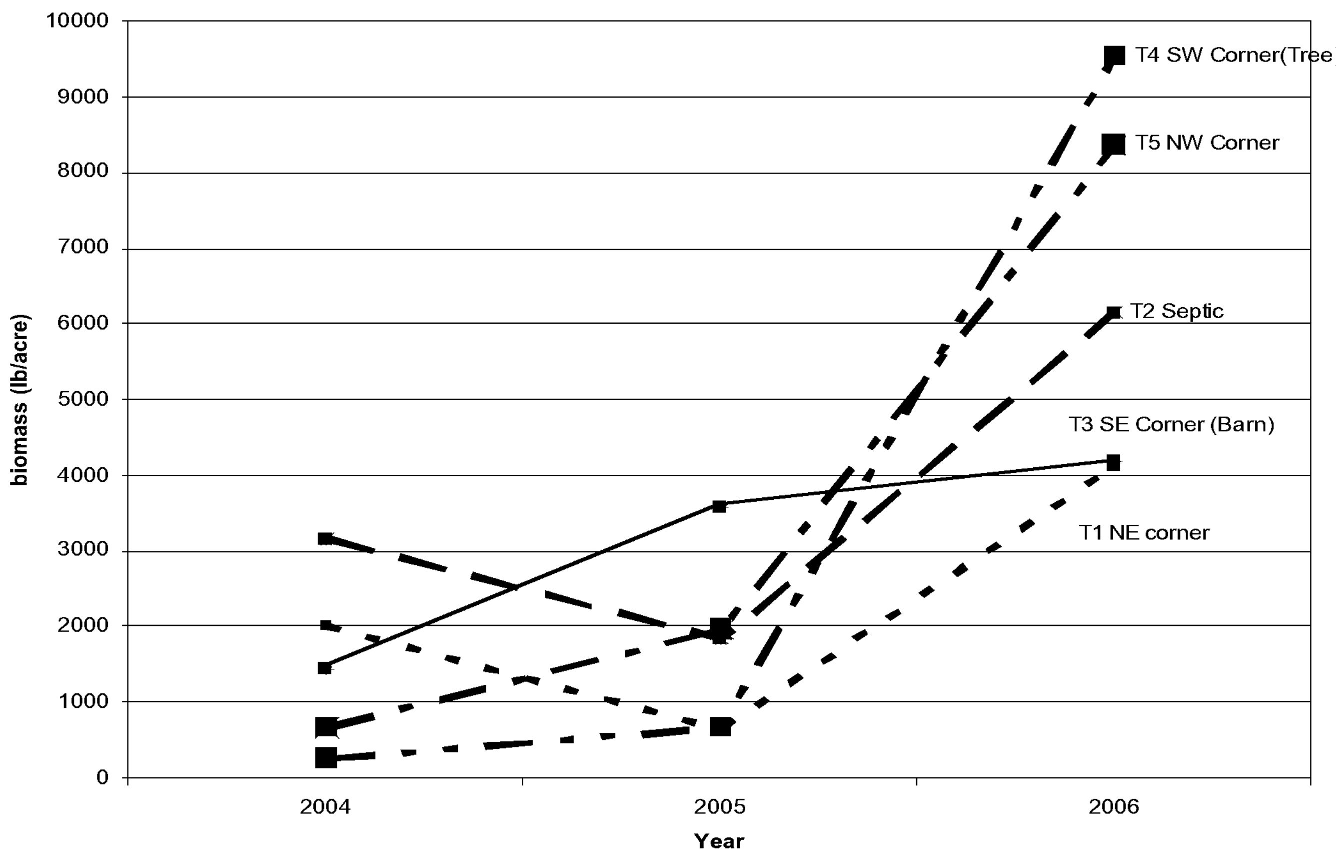

Figure 2. Biomass production in the long-term perennial grassland at Columbia Basin Agricultural Research Center, Pendleton, Oregon.

heads/ft^2 in fertilized crops, the same as in 2005. Spikelets/head were significantly increased by fertilization in all monocultures and significantly so in tilled spring wheat and untilled winter wheat. Kernels/head were not significantly affected by fertilizer except in the no-till winter wheat where kernels/head were significantly improved by fertilization. Grain protein was increased in all monocultures by fertilization. Only in the tilled winter wheat was this effect not significant. Nitrogen uptake {[(grain yield in lbs/acre)*(percent grain protein)]/570} in unfertilized monocultures ranged from 31 to 52 percent that of fertilized monocultures. This was significant in all treatments.

Conventional tillage

Conventionally tilled fertilized spring barley yielded significantly more than fertilized winter and spring wheat (Tables 9 and 10). Fertilized spring wheat yields were not significantly different from winter wheat. Among the conventionally tilled unfertilized plots, spring barley produced significantly greater yields than winter and spring wheat. Unfertilized winter wheat produced similar grain yield to unfertilized spring wheat. The positive correlation of yield and head density ($r = 0.57$, $P < 0.05$) and the negative correlation of spikelets/head ($r = -0.52$, $P < 0.05$) and kernels/head ($r = -0.59$, $P < 0.05$) indicate that terminal drought may have played a part in the lower yields of winter and spring wheat relative to spring barley. Spring barley reached physiological maturity on July 20th while spring wheat was not physiologically mature until July 26th. Winter wheat reached maturity on July 20th also but had probably exhausted the available soil moisture at that time. Fertilized spring wheat had significantly greater grain protein than fertilized spring barley and fertilized winter wheat. Fertilized spring barley and fertilized winter wheat had similar grain protein. Unfertilized spring and winter wheat had significantly greater grain protein than unfertilized spring barley. Unfertilized spring and winter wheat had similar grain protein. Unfertilized crops had similar N uptake. Fertilized spring barley had significantly greater N uptake than fertilized winter wheat. The N uptake of fertilized spring wheat was intermediate between the two.

No-till

No-till spring wheat, spring barley, and winter wheat responded to conditions in 2006 very much like conventional till monocultures. Spring barley, both in fertilized and unfertilized monocultures, significantly outyielded spring and winter wheat. Crop yield was positively correlated with head density ($r = 0.85$, $P < 0.05$). Grain protein and N uptake effects also followed the same trends in no-till monocultures as the tilled monocultures described above.

Conventional tillage v. no-till

Conventional-till crops yielded more than no-till crops. Yield differences were significant only in the fertilized winter wheat and the unfertilized spring barley monocultures. This may be attributed to greater head density ($r = 0.73$, $P < 0.05$) in the tilled monocultures of fertilized winter wheat and unfertilized spring barley. Stands in conventional-till crops tended to be denser than stands in no-till crops but not significantly so (data not presented). In fertilized monocultures the tilled treatments had grain protein levels of 0.6 to 1.4 percent lower than their no-till counterparts (Table 9). This effect was only significant in winter wheat (data not presented). In unfertilized monocultures the tilled treatments had grain protein levels of 0.5 to 0.9 percent higher than untilled treatments although this effect was not significant (Table 9). Nitrogen uptake was not significantly different between tilled and no-till monocultures.

Table 9. Comparisons of no-till and conventional till monocultures with and without nitrogen fertilizer at Columbia Basin Agricultural Research Center, Pendleton, Oregon.

	Fertility	Stand count	Combine yield	Bundle yield	Grain protein	Nitrogen uptake[1]	Test weight[2]	1,000 kernel weight combine grain	1000 kernel weight bundle grain	Harvest index	Heads per ft^2	Spikelets per head	Kernels per head	Downy brome
		plants/ft^2	bu/acre	bu/acre	%		lb/bu	oz	oz					plants/ft^2
CTCWW[3]	+ N	17.2	57.1	57.8	11.4	68.5	57.0	1.18	1.24	0.33	27.0	26.8	29.1	0
	- N	20.0	31.1	27.7	10.3	33.6	56.3	1.16	1.22	0.30	42.2	25.1	31.3	0
CTCSW	+ N	22.1	51.7	48.2	14.2	77.0	55.0	0.86	0.76	0.31	53.3	27.6	26.7	0
	- N	19.9	36.1	30.2	10.6	40.3	59.6	1.25	1.17	0.30	29.9	20.1	24.1	0
CTCSB	+ N	20.2	93.3	69.3	10.9	85.7	48.4	1.06	1.18	0.40	73.4	15.7	12.1	0
	- N	18.4	51.5	51.2	8.9	38.6	47.7	1.03	1.07	0.41	60.0	14.9	11.7	0
NTCWW	+ N	15.2	48.0	52.0	12.8	65.1	53.5	0.92	0.98	0.35	35.3	25.2	35.4	0.7
	- N	14.9	25.1	24.3	9.8	26.0	56.3	1.03	1.21	0.30	22.3	21.3	22.8	1.6
NTCSW	+ N	19.8	48.3	45.6	15.2	77.0	54.6	0.72	0.79	0.37	53.8	23.8	26.6	0
	- N	18.3	29.5	35.1	9.5	29.7	57.9	1.08	1.27	0.42	29.1	20.7	22.2	0
NTCSB	+ N	18.2	92.1	68.1	11.5	89.0	46.3	0.92	1.03	0.36	74.6	18.1	15.3	0
	- N	15.5	40.7	50.4	8.0	27.6	49.7	1.06	1.10	0.55	42.4	16.3	16.7	0

[1]Nitrogen uptake ((yield lb/acre)*(% grain protein))/570.
[2]One bushel of wheat equals 60 lb. One bushel of barley equals 48 lb.
[3]CTCWW = conventional tillage continuous winter wheat.
CTCSW = conventional tillage continuous spring wheat.
CTCSB = conventional tillage continuous spring barley.
NTCWW = no-tillage continuous winter wheat.
NTCSW = no-tillage continuous spring wheat.
NTCSB = no-tillage continuous spring barley.

Table 10. Statistical comparisons of mean combine yield under different continuous cereal cropping systems in 2006 (Pr > t) at Columbia Basin Agricultural Research Center, Pendleton, Oregon.

	CTCWWF	CTCSWF	CTCSBF	CTCWWNF	CTCSWNF	CTCSBNF	NTCWWF	NTCSWF	NTCSBF	NTCWWNF	NTCSWNF
CTCSWF[1]	ns[2]										
CTCSBF	****	****									
CTCWWNF	****	****	****								
CTCSWNF	****	***	****	ns							
CTCSBNF	ns	ns	****	****	***						
NTCWWF	*	ns	****	***	**	ns					
NTCSWF	*	ns	****	****	**	ns	ns				
NTCSBF	****	****	ns	****	****	****	****	****			
NTCWWNF	****	****	****	ns	*	****	****	****	****		
NTCSWNF	****	****	****	ns	ns	****	****	****	****	ns	
NTCSBNF	***	*	****	*	ns	*	ns	ns	****	***	**

[1]CTCWWF = conventional tillage, continuous winter wheat, fertilized.
CTCSWF = conventional tillage, continuous spring wheat, fertilized.
CTCSBF = conventional tillage, continuous spring barley, fertilized.
CTCWWNF = conventional tillage, continuous winter wheat, no fertilizer.
CTCSWNF= conventional tillage, continuous spring wheat, no fertilizer.
CTCSBNF = conventional tillage, continuous spring barley, no fertilizer.
NTCWWF = no-tillage, continuous winter wheat, fertilized.
NTCSWF = no-tillage, continuous spring wheat, fertilized.
NTCSBF = no-tillage, continuous spring barley, fertilized.
NTCWWNF = no-tillage, continuous winter wheat, no fertilizer.
NTCSWNF = no-tillage, continuous spring wheat, no fertilizer.
NTCSBNF = no-tillage, continuous spring barley, no fertilizer.

[2]ns = means not significantly different; *, **, ***, and **** = means significantly different at the 0.05, 0.01, 0.001, and 0.0001 levels of probability.

Crop Residue Management Experiment

Treatment had no significant effect on plant stand, which varied from 17 to 22 seeds/ft^2 (Table 11). No downy brome was present in these plots and surface residue after seeding was insignificant. Combine grain yield and bundle grain yield were highly correlated (r = 0.87, $P < 0.0001$). Manure plots had the highest yields, followed by the no-burn N treatments, spring-burn N treatments, and pea vine treatments. Nonfertilized checks and spring- and fall-burn treatments had the lowest yield. The yield of the 80- and 40-lb N spring-burn treatments were significantly different from no-burn treatments. The 80-lb N treatments yielded significantly more than the 40-lb N treatments. Grain yield was significantly correlated with heads/ft^2 (r = 0.61, $P < 0.0001$), test weight (r = 0.62, $P < 0.0001$), grain protein (r = 0.70, $P < 0.0001$), and N uptake (r = 0.95, $P < 0.0001$). Treatment significantly affected grain protein, N uptake, test weight, head density, and spikelets/head. Greater N input and lack of burning of crop residue tended to increase N uptake, test weight, head density, and spikelets/head.

Tillage Fertility Experiment

Data from the tillage fertility experiment are obtained in alternate years. No data are available as plots were in fallow in 2006.

Table 11. Crop residue experiment data for 2006 at Columbia Basin Agricultural Research Center, Pendleton, Oregon.

	Treatment	Stand count	Combine yield	Bundle yield	Test weight	1,000 kernel weight combine grain	1,000 kernel weight bundle grain	Harvest index	Heads per ft^2	Spikelets per head	Kernels per head	Grain protein	N uptake **
		plants/ft^{2*}	bu/acre	bu/acre	lb/bu	oz	oz					%	
Check 1	1	17.1b	46.4f	40.2d	57.3d	1.21a	1.33c	0.332a	26.8cd	25.3bc	28.5b	7.6e	37.0f
Check 10	10	21.9a	47.3f	49.9cd	57.0d	1.26a	1.34bc	0.355a	33.9bcd	25.4bc	27.8b	7.4ef	36.5f
Spring burn 40lbN/A	2	19.0ab	55.0e	61.8bc	58.5c	1.21a	1.34bc	0.375a	37.2ab	23.6c	28.4b	9.2c	53.2e
Spring burn 80lbN/A	3	19.0ab	62.6d	62.0bc	59.9a	1.16a	1.37abc	0.415a	32.8bcd	27.0ab	31.7ab	10.8a	71.1c
40lbN/A	4	19.1ab	60.4d	65.3b	58.7c	1.16a	1.36abc	0.372a	35.7abc	25.2bc	31.5ab	9.6c	60.8d
80lbN/A	5	19.8ab	66.8c	62.8bc	59.6ab	1.19a	1.42ab	0.380a	34.8abcd	27.1ab	29.1b	11.0a	77.4b
Fall burn	6	19.8ab	40.8g	42.5d	56.7d	1.21a	1.38abc	0.330a	27.9cd	28.1ab	28.2b	7.1ef	60.4g
Spring burn	7	18.6ab	41.6g	39.5d	57.3d	1.20a	1.39abc	0.328a	25.8d	26.5abc	23.8b	7.0f	30.8g
Manure	8	19.2ab	89.7a	92.4a	58.4c	1.24a	1.42a	0.415a	43.5a	28.6a	31.2ab	10.2b	96.1a
Pea vine	9	20.3ab	76.4b	81.2a	59.1bc	1.19a	1.40abc	0.392a	38.7ab	28.9a	37.2a	8.6d	69.1c

* Means with the same letters are not significantly different at the 0.05 probability level.
** Nitrogen uptake ((yield lb/acre)*(percent grain protein))/570.

Table 12. Wheat/pea rotation data for 2006 at Columbia Basin Agricultural Research Center, Pendleton, Oregon.

	Treatment	Stand count	Combine yield pea or wheat	Bundle yield pea or wheat	Grain protein	Nitrogen uptake **	Test weight	1,000 kernel weight: combine grain	1000 kernel weight: bundle grain	Harvest index	Pods or heads/ ft^2	Pods/ plant, or spikelets/ head	Seeds/pod or kernels/ head	Downy brome
		plants/ ft^{2*}	lb/acre, or bu/acre	bu/acre, or lb/acre	%		lb/bu	oz	oz					plants/ ft^2
PEA														
Fall plow	2	8.3a	2218.8c	2456.1b	*	*	64.2b	1.99a	1.71c	0.49b	39.2a	4.8b	4.1a	0a
Spring plow	3	8.5a	2483.9b	2987.1a	*	*	64.4ab	2.02a	1.85a	0.52a	39.8a	5.0b	4.6a	0a
Disk after wheat	1	8.5a	2562.0ab	2953.0a	*	*	64.2b	1.96a	1.75bc	0.49b	44.7a	5.1b	4.2a	0a
No-till	4	6.7b	2655.4a	2870.9a	*	*	64.5b	1.96a	1.71c	0.48b	43.6a	7.1a	4.1a	0a
WHEAT														
Fall plow	2	18.6a	64.4a	63.1a	12.7bc	85.7a	55.3ab	1.08a	1.06a	0.34a	39.6ab	27.4a	38.4a	0b
Spring plow	3	17.3ab	64.1a	62.5a	12.5c	84.0ab	55.4a	1.11a	1.11a	0.36a	37.2b	28.0a	35.6a	0b
Chisel after peas	1	17.6ab	61.2a	62.5a	12.9b	82.9ab	54.6b	1.08a	1.10a	0.35a	42.6a	28.4a	34.6a	0.5b
No-till	4	16.0b	55.0b	56.5a	13.8a	80.1b	51.7c	0.87b	0.94b	0.33a	39.0ab	28.9a	40.4a	5.1a

* Means with the same letters are not significantly different at the 0.05 probability level. Means compared separately for peas and wheat.
** Nitrogen uptake ((yield lb/acre)*(percent grain protein))/570

Table 13. Yields and test weights of continuous no-till winter wheat trial (USDA), 1998-2006, at Columbia Basin Agricultural Research Center, Pendleton, Oregon.

	Crop year								
	1998	1999	2000	2001	2002	2003[1]	2004	2005	2006
Planting date	Oct 24	Oct 15	Oct 15	Oct 18	Oct 25	Oct 28	Oct 28	Oct 22	Oct 30
Test weight (lb/bu)	60.0	59.9	61.0	58.5	56.5	57.2	55.7	55.8	55.6
Combine yield (bu/acre)	82.0	65.8	84.3	65.2	55.0	61.3	82.5	69.3	69.1
Crop-year precipitation (in)	15.0	16.9	18.7	15.7	12.6	15.2	15.0	12.0	18.8
Winter precipitation (in)	8.8	12.4	11.4	10.1	7.8	10.3	8.8	5.3	9.7
Spring precipitation (in)	6.3	4.4	7.3	5.7	4.9	4.9	6.3	6.6	9.1

[1]Clearfield winter wheat.

Wheat/Pea Rotation

Pea

Stands were not significantly affected by treatment but no-till plots had significantly lower plant density than other treatments. Stands ranged from 6.7 plants/ft^2 for no-till treatments to 8.5 plants/ft^2 for spring plow and disk treatments (Table 12). No downy brome or other significant weeds were present in these plots. Combine and bundle yields were highly correlated (r = 0.85, $P < 0.01$). Bundle yields include seed that shattered and was picked up off the ground. To this end, bundle yields are discussed below. No-till, spring plow, and disk treatments produced significantly higher yields than the fall plow treatment (Table 12). Standing stubble and surface residue left over winter may have contributed to increased water storage over winter in these treatments, which is particularly important in a spring-sown short-season crop like dry field peas. No-till plots had lower plant populations but compensated by producing more pods per plant. Bundle grain yields were significantly correlated with kernel weight (r = 0.51, $P < 0.0001$), and pods/ft^2 (r = 0.60, $P < 0.01$). Treatment did not significantly affect kernel weight and pods/ft^2.

Wheat

Combine and bundle yields were strongly correlated (r = 0.96, $P < 0.0001$). Combine yields are discussed below. The fall plow treatment had a significantly higher number of plants/ft^2 than the no-till treatments (Table 12). Plant stands were not significantly different between chisel after peas and spring plow treatments. Stand was negatively correlated with kernels/head (r = -0.43, $P < 0.05$). Grain yield was significantly affected by treatment, with the no-till treatment yielding significantly less than all other treatments. Downy brome infestation was significantly affected by treatment; the no-till treatment had significantly higher populations than all other treatments (5.1 plants/ft^2). It is possible that factors in addition to this downy brome contributed to reduced yields in the no-till treatment. Yield was positively correlated with test weight ($r = 0.64$, $P < 0.0001$), and kernel weight ($r = 0.57$, $P < 0.0001$. Yield was negatively correlated with kernels/head ($r = -0.43$, $P < 0.05$) and grain protein ($r = -0.61$, $P < 0.0001$). Treatment affected downy brome populations, kernel weight, test weight, and grain protein. Grain protein of the no-till treatment was significantly greater than all other treatments (13.8 percent)

Continuous No-till Winter Wheat (USDA)

Yield and test weight data from 1998 to 2006 are shown in Table 13. Grain yield was poorly correlated with winter precipitation ($r = 0.10$, $P < 0.05$), and only partly correlated with spring precipitation ($r = 0.47$, $P < 0.05$) and total crop year precipitation ($r = 0.37$, $P < 0.0$.

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Planting Date and Seeding Rate Effects on the Yield of Winter and Spring Wheat Varieties – Results from the 2005-2006 Cropping Year

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Abstract

The economic viability of Oregon wheat production depends on highly productive varieties and cost-effective sustainable management practices. Growers are continuing to adopt newly released varieties; however there are few available data on how to best incorporate these varieties into individual production systems. Growers are also exploring new management practices such as fall seeding of spring wheat varieties to take advantage of market opportunities. Clearly, information on these newer varieties and management practices is needed. Therefore, a study was initiated in the fall of 2005 to evaluate the performance of four newer Oregon winter wheat varieties compared to 'Stephens' and 'Madsen'. Two study sites were established at Pendleton and Moro, Oregon. The study evaluated variety performance across four planting dates and three seeding rates. The study found that planting date had the greatest effect on yield. Delayed plantings reduced yields by up to 24 percent. Further analysis found that there was no variety by seeding rate interaction, indicating that all varieties performed similarly across seeding rates. Among varieties, 'Tubbs' yielded as well or better than 'Stephens' across all planting dates. 'ORCF-102' was found to perform well in late plantings. The soon-to-be-released variety 'ORH010920' was found to have highly variable results due to its facultative nature, indicating that this variety is not as broadly adapted as hoped. We found that, among seeding rates, increased seeding rates can increase yield by up to 5 bu/acre in late plantings at Moro. However at Pendleton, it would not have been beneficial to increase seeding rates above 22 seed/ft^2. A complementary study on spring wheat was also established in 2004. This study compared several spring wheat varieties to the winter wheat 'Tubbs'. Three fall planting dates and a single spring planting date were evaluated. Our results indicate that the spring wheat varieties yielded as much as 'Tubbs' in plantings after November 1.

Key words: seeding date, seeding rate, spring wheat, winter wheat

Introduction

The most important agronomic decision that growers make is varietal selection. Selecting an appropriate variety minimizes risk from crop diseases and stresses while maximizing yield potential. Growers and crop consultants commonly use statewide variety trials, local extension trials, and/or private company variety trials as sources of information on variety performance. While these trials are useful in comparing varieties in a common setting, they provide few data to growers on how these varieties may fit in their individual production systems.

Under favorable moisture conditions in eastern Oregon, growers may start planting winter wheat in late August or early September. Due to the typically dry fall weather, many growers may not finish planting until late October or early November. Within this large planting window, the crop production challenges that growers face change over time. Early planted wheat has a higher yield potential than later plantings (Thill et al. 1978). However, crop diseases such as Cephalosporium stripe, strawbreaker foot rot, and barley yellow dwarf virus can be major production challenges. Growers can minimize the risk of these diseases and other pests or stresses by selecting appropriate varieties for early planting conditions.

Weather is the primary factor that drives late plantings. In many years growers must wait for rain to have adequate moisture to seed or for "dusted in" seeds to germinate. Due to the reduced time for growth and development, these late plantings have reduced yield potential compared to earlier plantings. Growers compensate for this difference by planting varieties that have a high tillering capacity or by increasing the seeding rate. Bohle et al. (2000) reported on the high tillering capacity of 'Stephens' wheat. They found that seeding rates had to be below 8 seeds/ft^2 to reduce yields. Similarly, Wysocki and Corp (2006) illustrated how increased seeding rates were required to meet yield expectations for later plantings.

Clearly, information on the performance of varieties under early and late plantings would benefit growers in determining how best to utilize these varieties within their individual production system. However, typical variety trials only compare varieties within a single planting date that is chosen to represent the normal "on-time" planting date for the local region. Thus there is no way to determine which varieties perform best under early or late planting.

Complicating the decision for growers is the continued introduction of new varieties into the marketplace. Currently, several newer varieties such as 'Tubbs', 'ORCF-101', and 'ORCF-102' have been successfully introduced into the marketplace. In 2005, these newer varieties accounted for over 20 percent of the total winter wheat acreage. Based on the success of these varieties and the performance of the elite lines currently in trials, there will continue to be an increase in plantings of these newer varieties. However, this creates a challenge for growers as little information is known on how these varieties perform when planted early or late. Currently, there is anecdotal evidence that suggests that 'Tubbs' does not yield as well as 'Stephens' in late plantings, but growers need production information on these newer varieties so they can make informed decisions when adapting these varieties into their production system.

Therefore, a series of experiments was initiated in 2004 and 2005 to evaluate both winter and spring wheat varieties under a range of planting dates. The winter wheat trials concentrated on the performance of newer soft white wheat varieties as well as the interaction of seeding rate and planting date. The spring wheat trials investigated whether the common practice of fall planting of spring types in the Treasure Valley region of Idaho was applicable to the Columbia Basin region of Oregon.

Materials and Methods

Winter Wheat Trials

Trial sites were positioned to represent a range of environmental and production conditions within Oregon's largest wheat producing region. Sites were located on the Columbia Basin Agricultural Research Center at Moro and Pendleton, Oregon. The Moro site is located in the

10- to 12-inch rainfall zone and has rolling hills with slopes of 3 to 30 percent. The soil is predominately Walla Walla silt loam (Typic Haploxerolls). The Pendleton trial is located in the 16-inch or greater rainfall zone and has gentle rolling hills with slopes ranging from 0 to 5 percent. The soil at the Pendleton location is also predominately Walla Walla silt loam.

At each site a randomized complete block design with three replications was used. Variety treatments consisted of six soft white winter wheat varieties (Table 1). Four newer or soon to be released Oregon varieties were compared to the two older standard varieties 'Stephens' and 'Madsen'. Each variety was evaluated under three seeding rate treatments, and three (Moro) or four (Pendleton) planting dates (Table 1). Soil tests were taken at each site to optimize preplant fertilizer application. Yield goals for nitrogen fertilizer were a 100 bu/acre at Pendleton and 60 bu/acre at Moro. In the fall, 5- by 20-ft research plots were established using a small plot drill. Establishment date varied according to planting date. Plots were harvested using a Hege® small plot combine and measurements of yield and test weight were obtained. Data were analyzed using SAS software and means were separated using least square means.

Table 1. Variety, seeding rate, and planting date treatments for the winter wheat and spring wheat trials, Columbia Basin Agricultural Research Center, 2005-2006.

Winter wheat trial treatments			
Varieties	**Seeding rates**	**Planting dates**	
	(seeds/ft^2)	**Moro**	**Pendleton**
Stephens	11	9/14	9/13
Madsen	22	10/5	10/4
Tubbs	33	10/28	10/27
ORCF-101			11/17
ORCF-102			
ORH010920			

Spring wheat trial treatments		
Varieties	**Seeding rate**	**Planting dates**
	(seeds ft^{-2})	
Tubbs	28	10/7
Jefferson		10/21
Zak		11/5
Alpowa		3/8

Spring Wheat Trials

This trial was established in the fall of 2004 at Pendleton. Three varieties of spring wheat and one variety of winter wheat were planted at 28 seeds/ft^2 using a Hege® small plot grain drill at three dates in the fall (Table 1). The spring varieties were planted on one date in the spring.

The treatments were arranged in a split plot design with planting dates as main plots and varieties as subplots; there were four replications. Fertilizer was applied based on soil test results and a yield goal of 80 bu/acre, and weeds were controlled by herbicides. The plots were harvested using a Hege® small plot combine and yield was estimated. Test weight was measured using subsamples from the grain yield samples. Data were analyzed using SAS software and the LSD values were calculated.

Results and Discussion

Winter Wheat Trials

The environmental conditions at each site led to significant differences between the sites. Therefore, the sites were separated into a high rainfall site (Pendleton) and a low rainfall site (Moro) for further analysis and discussion.

High Rainfall – Pendleton

Planting date had the largest impact on grain yield. The "on-time" planting (October 4) had a mean grain yield of 100.9 bu/acre. All three other planting dates had significantly lower grain yields (Fig. 1A). Grain yields were reduced by 23.6 and 17.0 bu/acre respectively for the October 27 and November 17 plantings. These yield reductions due to delayed planting agree with previous studies that have shown similar yield reductions (Thill et al. 1978). The early planting date (September 13) had a mean grain yield that was 9.1 bu/acre lower compared to the October 4 planting. In practice, earlier plantings usually increase grain yield in growers' fields. The yield reductions found for early planting in this study are likely due to equipment limitations that prevented seeding deep enough to reach moisture. This resulted in the spotty emergence and stands documented in the trial. Emergence is typically more uniform in growers' fields because they have deep furrow drills that allow them to seed into moisture and achieve more uniform stands. Thus it is likely that the 9–10 percent yield reduction due to early planting found in this study would have occurred in growers' fields.

To remove the effects of planting date, variety and seeding rate were separated by planting date for further analysis. There was not a significant interaction between variety and seeding rate, indicating that within a planting date all the varieties evaluated performed similarly across the seeding rate treatments. Among varieties, 'Tubbs' wheat had a significantly higher grain yield compared to the other varieties for the early planting date (September 13; Fig. 1A). 'Tubbs' wheat outyielded the next closest variety 'Stephens' by 9.7 bu/acre. 'Tubbs' wheat also yielded well across the other three planting dates and in no instances was its grain yield significantly lower than 'Stephens'. This contradicts the anecdotal evidence that suggested 'Stephens' outyields 'Tubbs' in late plantings. Other notable results among varieties were the good performances of 'ORCF-102' and the soon to be released 'ORH010920'. Both varieties were among the highest yielding varieties for the last three planting dates. However, growers should be aware of the poor performance of both 'Madsen' and 'ORCF-101' under late plantings. Both of these varieties had significantly lower yields compared to the other varieties for the last two planting dates. Yield reductions for these varieties were up to 15.4 bu/acre.

There were few significant differences among seeding rates for grain yield (Fig. 1B). The 11 seeds/ft^2 treatment had a significantly lower yield compared to the 33 seeds/ft^2 treatment for the

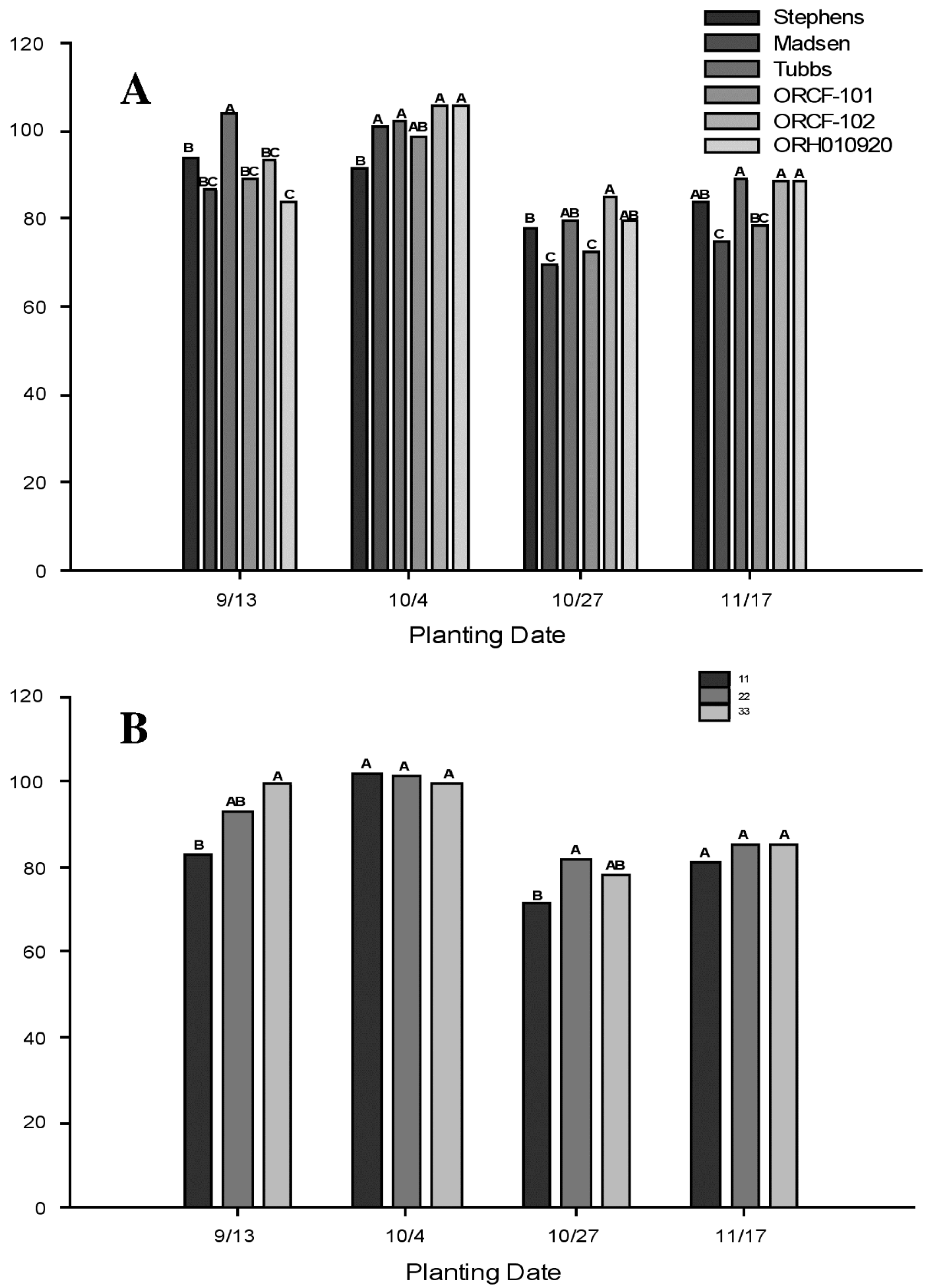

Figure 1. Grain yield differences among (A) winter wheat variety and (B) seeding rate treatments at Pendleton, Columbia Basin Agricultural Research Center, 2005-2006. Means followed by the same letter are not significantly different at the 0.05 level.

September 13 planting date. The 11 seeds/ft^2 treatment also had a significantly lower grain yield compared to the 22 seeds/ft^2 treatment for the October 27 planting date. There were no significant differences among seeding rate treatments for either the October 4 or November 17 planting dates. These results indicate that all of the varieties evaluated have the ability to compensate for variations in seeding rate. Further evaluation of the yield components is needed to determine the exact mechanism of compensation (wheat may compensate through tillering, head size, and/or seed size).

Low Rainfall – Moro

Planting date also had the greatest impact on grain yield under the low rainfall conditions at Moro (Fig. 2A). The "on-time" (October 5) planting had a mean grain yield of 74.8 bu/acre. There was no significant difference in grain yield between the early (September 14) and "on-time" (October 5) plantings. Delaying planting (October 28) reduced grain yield by 36 percent compared to the October 5 planting. This resulted in a 27.1 bu/acre reduction in grain yield.

To remove the effects of planting date, variety and seeding rate were separated by planting date for further analysis. There was not a significant interaction between variety and seeding rate, indicating that within a planting date all the varieties evaluated performed similarly across the seeding rate treatments. Both the September 14 and October 5 planting dates had high grain yields (Fig. 2A). Among varieties, 'Madsen' had significantly lower grain yields compared to all the other varieties for both the September 14 and October 5 planting dates, whereas 'ORH010920' yielded significantly higher than the other varieties for the October 5 planting date. The yield advantage of 'ORH010920' compared to the next highest variety 'ORCF-101' was 4 bu/acre. For late plantings (October 28), 'ORCF-102' had a significantly higher yield compared to all other varieties. Surprisingly, 'ORH010920' had the lowest yield for this planting date. Recently, 'ORH010920' was found to be fully facultative in nature and had poor cold tolerance. The low yield in the October 28 planting date is likely due to these characteristics.

There were several significant differences among seeding rate treatments at Moro (Fig. 2B). The 11 seeds/ft^2 treatment had significantly lower yields compared to the 33 seeds/ft^2 treatment across all three planting dates. The most notable difference was the significant increase in yield at the high seeding rate for the late planting date (October 28). This resulted in a 4.9 bu/acre increase in yield for the 33 seeds/ft^2 seeding rate. Clearly, in this instance a higher seeding rate would have been justified.

Spring Wheat Trials

In this trial both spring and winter wheat varieties were evaluated across a range of planting dates. The winter wheat 'Tubbs' performed similarly to the Pendleton trial outlined above. Grain yield was reduced by 19 percent as planting date was delayed from October 7 to November 5 (Fig. 3). The spring wheat varieties followed a different pattern. A late fall (October 21 or November 5) planting maximized grain yield, while planting earlier (October 7) reduced yields by 14 percent. Delaying planting until the spring of the following year (March 8) also reduced yields by 14 percent.

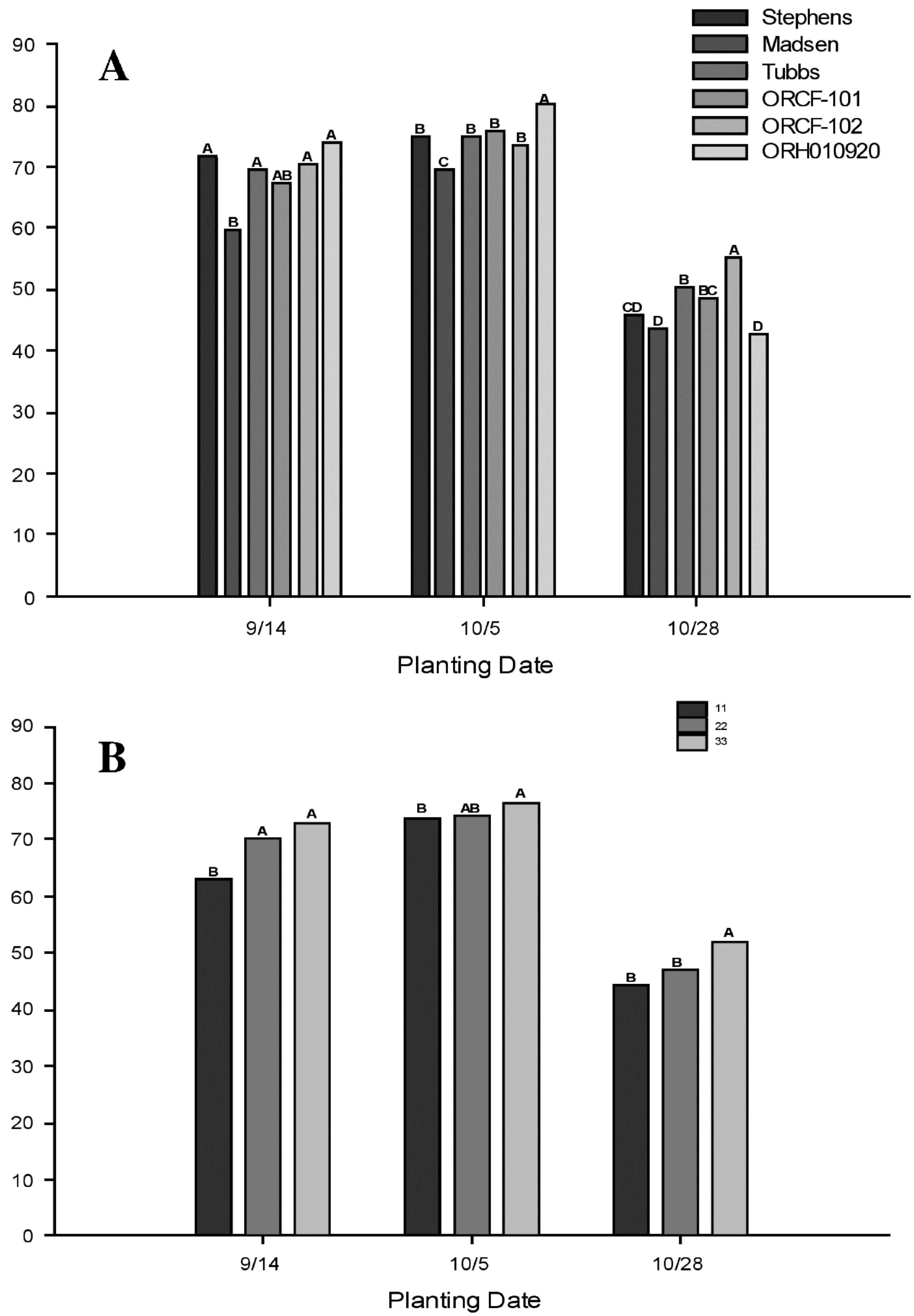

Figure 2. Grain yield differences among (A) winter wheat variety and (B) seeding rate treatments at Pendleton, Columbia Basin Agricultural Research Center, 2005-2006. Means followed by the same letter are not significantly different at the 0.05 level.

To remove the effects of planting date, variety was separated by planting date for further analysis. Among varieties, 'Tubbs' winter wheat had significantly higher yields than any of the spring wheat varieties for the October 7 and October 21 planting dates (Fig. 3). For the October 7 planting date 'Tubbs' outyielded the closest spring wheat variety 'Zak' by 24 bu/acre. While the spring wheat varieties increased their yields for the October 21 planting date, 'Tubbs' still outyielded the closest spring wheat 'Jefferson' by 17.4 bu/acre. By early November, all the spring wheat varieties had yields equal to 'Tubbs'. This would agree with results from the Treasure Valley region, where spring wheat varieties are planted starting in November as they yield as well or better than winter wheat varieties planted at the same time. For the spring planting date (March 8) the variety 'Jefferson' had significantly higher yield compared to both 'Zak' and 'Alpowa'.

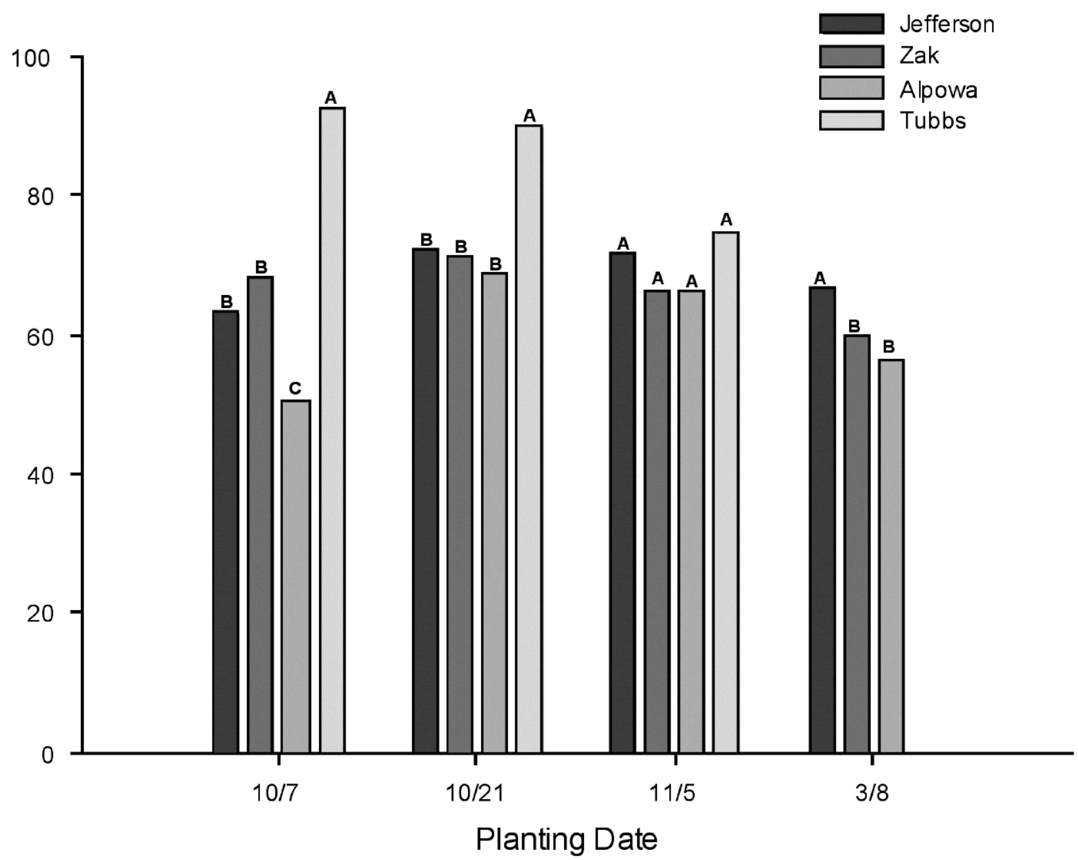

Figure 3. Grain yield differences among winter and spring wheat varieties at Pendleton, Columbia Basin Agricultural Research Center, 2005-2006. Means followed by the same letter are not significantly different at the 0.05 level.

Conclusions

Several conclusions can be drawn from these trials. Among the management factors studied for winter wheat, planting date was found to have the largest effect on yield. Delaying planting after early October reduced yields up to 24 percent (Figs. 1 and 2). Therefore, growers should strive for timely plantings to maximize yield and profit.

Among varieties, it is clear that the newer varieties perform equal to or better than the older varieties 'Stephens' and 'Madsen' (Figs. 1 and 2). These data agree with the statewide variety trials and illustrate why growers are adopting these newer varieties. Also it is clear from the data that 'Tubbs' yields higher than or equal to 'Stephens' across the range of planting dates studied. This contradicts the anecdotal evidence from growers in the region who found that 'Stephens' outperformed 'Tubbs' in late plantings. Further, the study results were independent of seeding rate, indicating that 'Tubbs' performed as well as 'Stephens' across the range in seeding rates evaluated. Therefore, increased seeding rates are not required for late plantings of 'Tubbs'. Further studies are underway to determine if these results are constant across years.

The results for the soon-to-be-released 'ORH010920' are also of interest. This variety is fully facultative, meaning it has no vernalization requirement, which led to highly variable results across sites and planting dates (Figs. 1 and 2). At Pendleton, 'ORH010920' performed well in later plantings but performed poorly in the early planting (September 13). Conversely, at Moro 'ORH010920' performed well in earlier plantings but did poorly in the late planting date (October 28). It is likely that cold temperatures in Pendleton set the early planted 'ORH010920' back, while the delayed emergence and shorter growing period in Moro reduced the variety's ability to tiller. Both resulted in lower yields for 'ORH010920'. These results, along with the recent statewide variety trials, indicate that this variety is not as broadly adapted as hoped and will need to be carefully integrated into a growers' production system.

The results for the two newer Clearfield® varieties 'ORCF-101' and 'ORCF-102' were also interesting. Both varieties performed well in early plantings; however 'ORCF-102' clearly outperformed 'ORCF-101' as well as many other varieties in late plantings at both sites (Figs. 1 and 2). Growers should consider 'ORCF-102' for late plantings.

Surprisingly, there was no interaction between varieties and seeding rates. There were also few significant differences among seeding rates. At Pendleton it was never beneficial to increase the seeding rate above 22 seeds/ft^2. However, at Moro, increasing the seeding rate to 33 seeds/ft^2 would have improved yield in late plantings by almost 5 bu/acre. Growers should consider increasing seeding rates for late plantings; however the effect depends on the environment and may not be significant in all years.

The spring wheat trial also provided some interesting results. Growers in the Treasure Valley region have been fall planting hard red spring wheat for several years. This allows them to take advantage of protein premiums of hard red spring while increasing yield potential by lengthening the growing season. The trial results in the Columbia Basin show that growers in this region may also be able to use this strategy. In late plantings (after November 1), spring wheat varieties had equal yields compared to soft white winter wheat. If these results can be repeated across years, this would offer Columbia Basin growers an alternative wheat class that has the potential for increasing profits when planting must be delayed by weather conditions.

The results of these studies are preliminary, but should give growers several insights into how to place these newer varieties or classes into their individual production systems. Currently the trials are being repeated to determine if the results from 2005-2006 will be consistent across years.

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Long-Term Experiments at Columbia Basin Agricultural Research Center at Moro and Center of Sustainability at Heppner, 2005-2006

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Abstract

This project has now completed 3 crop years of experimentation. Three more crop years are required for all crop rotations to complete a full cycle. This report covers the 2005-2006 crop-year results. Columbia Basin Agricultural Research Center (CBARC) experiment (Moro): Spring barley produced the highest yields followed by yields of winter wheat after conventional fallow or winter wheat after chemical fallow in a 3-year rotation with spring barley. Yields of winter wheat following chemical fallow (2-year rotation) were significantly lower than yields of continuous spring barley and winter wheat after conventional fallow or after chemical fallow in a 3-year rotation with spring barley. Continuous winter wheat had the lowest yields, probably due to a combination of weeds (downy brome) and diseases (Fusarium crown rot and root-lesion nematodes) but not due to a shortage of water. On average (2004-2005 and 2005-2006), wheat following chemical 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 or chemical fallow (2-year rotations). In rotations involving annual cropping, continuous spring barley produced the highest yields followed by winter wheat after winter pea. Continuous winter wheat produced the lowest yields over the 2 crop years. Center of Sustainability (Heppner): Continuous spring barley produced the highest grain yields followed by winter wheat following fallow (conventional or chemical). The lowest yield was obtained from continuous spring wheat.

Introduction

The winter wheat-summer fallow rotation reduces soil organic carbon, exacerbates soil erosion, and is not biologically sustainable. Despite these concerns, adoption of alternate cropping systems, such as intensive cropping and direct seeding, has been slow due to lack of long-term research on viability of alternate cropping systems in Oregon. Occasional crop failures occurred under long-term conventional intensive cropping studies conducted at the Sherman Experiment Station in the 1940's to the 1960's. But with the advent of new varieties and agronomic practices such as direct seeding, long-term research is needed to evaluate benefits and risks for annual cropping. The main focus of the experiment is to establish and maintain long-term experiments that compare the conventional wheat-fallow system with alternate cropping systems that use crop management practices such as direct seeding, which reduce wind and water erosion. Specific objectives are to increase residue cover, increase soil organic matter, increase available soil moisture, reduce soil erosion, reduce soil water evaporation, and sustain crop productivity. This research is targeted for Agronomic Zones 4 and 5 in northcentral Oregon.

Methods and Materials

CBARC, Moro

The experiment was established on a 28-acre site at the Sherman Experiment Station in Moro in the fall of 2003. The experiment has completed 3 crop years (2003-2004, 2004-2005, and 2005-2006). The soil is a Walla Walla silt loam (coarse, silty, mixed, mesic Typic Haploxeroll) and is greater than 4 ft deep. The station receives an average of 11.5 inches of annual precipitation. Rainfall and soil at the station are representative of the average conditions in the target area.

Treatments

Crop rotations under evaluation are shown in Table 1. Each phase of each rotation appears every year. The treatments are replicated three times. There are 14 plots per replication and the minimum plot size is 48 ft by 350 ft, bringing the minimum total experimental area to 13.88 acres. Agronomic practices (planting date, planting rate, and fertilizer, herbicide, seed-treatment fungicide, and insecticide application) are based on the treatment in question. Direct seeding is conducted using the Fabro® drill (Fabro Enterprises Ltd., Swift Current Saskatchewan) purchased with assistance from the Sherman Station Endowment Fund.

Table 1. Cropping system treatments at the Sherman County Experiment Station, Moro, Oregon.

Rotation	Description
1	Winter wheat–conventional fallow (2 strips in rotation)
2	Winter wheat–chemical fallow (2 strips)
3	Continuous winter wheat (1 strip)
4	Continuous spring wheat (1 strip)
5	Continuous spring barley (1 strip)
6	Winter wheat–spring cereal (barley)–chemical fallow (3 strips)
7	Winter wheat–winter pea (2 strips)
8	Flex crop (2 strips)

Field operations: Winter wheat ('Stephens') for rotation 1 was seeded on October 10, 2005, using the HZ drill at 18 seeds/ft^2 (88 lbs/acre). 'Stephens' wheat for rotations 2, 3, 6, and 7 was direct-seeded at 20 seeds/ft^2 (98 lbs/acre[1]) at a depth of about 1 inch on October 19 and 20, 2005, using a Fabro® drill. Different fertilizer rates were applied to plots of different rotations to bring up the nitrogen (N) levels to 80 lbs N/acre. Fertilizer rates ranged from 30 to 70 lbs N/acre. Winter pea ('Spector') for rotation 7 was direct-seeded at the rate of 7 peas/ft^2 (85 lbs/acre) on October 15, 2005. Granular inoculant was applied with the seed at the rate of 57 grams/1,000 ft of row. About 10 lbs N/acre was applied at seeding. Spring barley ('Camas') for rotations 5 and 6 was direct-seeded on April 12 and 13 at 22 seeds/ft^2. Spring wheat ('Louise') for rotation 4 was direct-seeded on March 30. Spring cereals received about 20 lbs N/acre. Using the Fabro® drill, seed was placed at a depth of 1 inch and fertilizer at 3 inches. For the two Flex crop treatments (rotation 8), 'Tilney' mustard and canola were direct-seeded at 10 lbs/acre using the Fabro® drill. Each phase of each rotation is present each year. Data on plant stand, phenology, weeds, and diseases were collected. At maturity, plots were harvested using a commercial combine with an 18-ft header. The 18-ft swath was taken right in the center of the 48-ft-wide plot. Grain was weighed using a weigh-wagon to determine yield per treatment.

Soil water measurements were taken throughout the growing season using a PR2® probe (Delta-T Devices Ltd. Cambridge, England). The probe senses the soil moisture content at 4-, 8-, 16-, 24-, and 40-inch depths by responding to dielectric properties of the soil. Readings were made on two access tubes in each plot. At each reading, two measurements were taken, each time with the probe rotated to a different direction.

Center of Sustainability

The experiment is located at the William Jepsen farm near Heppner, Oregon. In the past 5 years the Center of Sustainability (COS) has evaluated cropping systems that are similar to the cropping systems at Moro (Table 1). The COS site receives similar crop-year precipitation to Moro (11 inches), but its soil is shallower (2 ft deep) than the Moro site (greater than 4 ft deep). This makes it possible to effectively determine the influence of soil depth on the alternate cropping systems. The cropping systems being evaluated at COS were modified in the 2003-2004 season to match most of the treatments at Moro. Data collection is the same as at Moro, but the experiment is not replicated. However, the experiment has very large plots that measure 80 ft by 900 ft and it may be possible to split the plots and add at least one replication. In the meantime, data will be analyzed using statistical methods for unreplicated studies (Perrett and Higgins 2006).

Table 2. Cropping and tillage systems under evaluation at the Center of Sustainability (COS) study at Bill Jepsen's farm near Heppner, Oregon.

Treatment/rotation	Description
1	Conventional winter wheat/conventional fallow
2	Winter wheat/chemical fallow–direct seeding
3	Continuous spring barley–direct seeding
4	Continuous spring wheat-direct seeding
5	Continuous spring DNS–direct seeding
6	Continuous winter wheat-direct seeding
7	Spring barley/mustard/spring wheat–direct seeding
8	Winter wheat/mustard/chemical fallow–direct seeding
9a	Flex crop
9b	Flex crop

Results and Discussion

Data on grain yield and pests that were collected in the 2005-2006 crop year are discussed in this report.

CBARC, Moro

Soil water measurements

Soil moisture content measurements (average of whole 40-inch profile) for each treatment, from March 3, 2006, to August 18, 2006, are shown in Figure 1. As expected, fallow treatments had the highest amount of moisture throughout this period. The winter wheat after chemical fallow treatment (rotation 2) had the lowest soil moisture from the start of the measurements to the end. Surprisingly, moisture content of plots under continuous winter wheat was higher than all cropped treatments beginning in June onwards. At the last measurement, the moisture of this treatment was 16 percent compared to 9 percent under winter wheat following chemical fallow. A closer look at soil water distribution in the 40-inch profile of this treatment (data not shown) shows that wheat in this treatment used water mostly from the top 8 inches and did not use as much water from the lower depths when compared to the other cropped treatments. This indicated that other factors were preventing wheat from extracting water at deeper profiles.

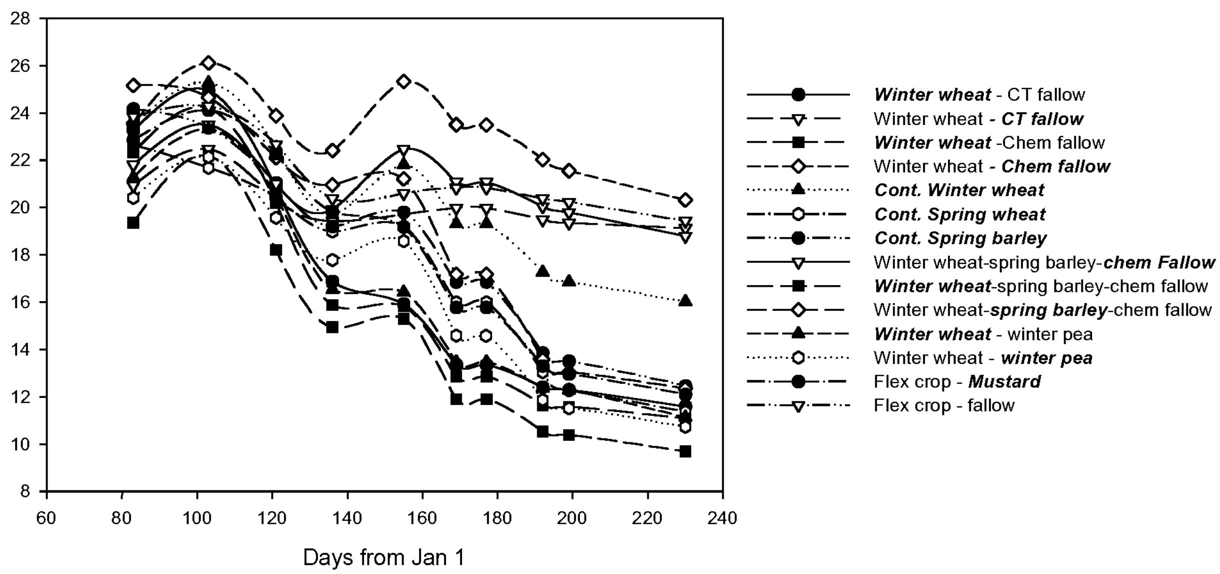

Figure 1. Average soil water content under all rotations in the 0- to 40-inch depth profile from March to August, 2006, at Columbia Basin Agricultural Research Center, Moro, Oregon.

Weeds

The weeds team evaluated downy brome (*Bromus tectorum*) and broadleaf weed control in the cropping systems under study. Weed plant counts were taken in March and May of each year. At the beginning of the study there were no significant differences in weed populations. Results in 2006 indicated that downy brome populations had increased in direct-seeded winter wheat, with a significant increase in recrop direct-seeded winter wheat (Table 3). These treatments were not treated for grass control in 2006. Downy brome populations in all other treatments declined to low levels (fewer than 0.5 plants/ft^2). All broadleaf weed species population numbers have declined in all treatments to fewer than 0.5 plants/ft^2.

Table 3. Downy brome populations in different cropping systems after herbicide treatment, Moro Long-term Experiment, 2004, 2005, 2006.

		Downey brome (plants/m^2)		
Treatment	Rotation	5/5/04	5/3/05	5/19/06
1[1]	1	5	2	6
2	1	0	1	0
3	2	4	2	12
4	2	0	2	0
5	3	8	11	20
6	4	0	0	0
7	5	0	0	2
8	6	8	0	0
9	6	0	0	0
10	6	0	5	0
11	7	8	0	8
12	7	2	1	0
13	8	0	0	0
14[3]	8	0	0	0
$LSD_{0.05}$		7	4	8

[1] Treatments No. 1, 3, 5, 9 and 11 did not receive a grass herbicide before May 19, 2006. Flex crop in 2004 was spring wheat, in 2005 it was spring barley, and in 2006 it was mustard.
[3] Treatment no.14 was plowed up in 2006.

Diseases

Diseases in fall- and spring-planted plots were assessed during late March and mid-June, respectively. Samplings consisted of 20 to 40 plants plus intact roots collected over the length of each plot, washing soil from the roots, and scoring each root system for incidence (percent plants) and severity (qualitative rating scale) of diseases such as Fusarium foot rot, take-all, and Rhizoctonia root rot. Plants were also examined for the presence or level of damage by other diseases and insect pests. Soil samples (about 20 cores/plot; 1-inch diameter by 12-inch depth) were collected in early April and sent to Western Laboratories (Parma, ID) for quantification of plant-parasitic nematode genera.

March 29, 2006 sampling

All three replicates of five winter wheat and one winter pea treatment were sampled. The incidence of lesions on subcrown internodes, caused by Fusarium crown rot, was high (30 percent) only on winter wheat following the traditional cultivated summer fallow. The severity indices for subcrown internode lesions also appeared higher in the conventional winter wheat-summer fallow rotation than in other treatments but this apparent difference was not statistically significant. There were also no statistical differences among treatments for the incidence and severity of Rhizoctonia root rot, take-all, and Fusarium crown rot symptoms on seminal roots. On crown roots, symptoms of the three root diseases occurred mostly in the conventionally tilled winter wheat-summer fallow rotation, but differences were not statistically significant at P = 0.05. Most of the important observations reported for fall-planted crops during this sampling in 2006 were consistent with observations reported 1 year earlier, during March 2005.

Cotyledons of winter pea that was rotated with winter wheat had a very minor occurrence of a blackening caused by *Thielaviopsis basicola*. A complex of *Rhizoctonia* and *Pythium* species caused lesions to occur on a high percentage (70 percent) of tap roots but the severity of lesion development was low to moderate. As during 2005, vascular browning caused by Fusarium wilt was not detected.

June 15, 2006 sampling

All replicates of one spring wheat, two spring barley, and one spring mustard (flex crop) treatments were sampled. No diseases were observed on spring mustard. The incidence of diseases on subcrown internodes and seminal roots of wheat and barley did not differ significantly among treatments. Nevertheless, there was a distinct trend for higher incidence of Rhizoctonia root rot on the barley than wheat, and an opposite trend for incidence of take-all. Rhizoctonia root rot was the only disease of importance on the coronal root system, and was significantly greater on barley than wheat.

Nematode observations for samples collected on April 4, 2006

Root-lesion nematodes were the primary plant-parasitic species detected in the soil samples collected shortly after spring crops were planted. Although not significant at P = 0.05, the population of root-lesion nematodes was considerably higher in rotations including winter wheat than other crops. Populations of root-lesion nematodes approximated or exceeded the estimated threshold for economic damage (900/lb of soil) in five treatments, each of which included winter wheat as a current or recent crop. These treatments were numbered 1 (winter wheat rotated with conventional summer fallow), 5 (annual direct-drill winter wheat), 10 (spring barley recently planted in soil following a winter wheat crop), 11 (winter wheat following winter pea), and 12 (winter pea following winter wheat). Populations were lower where winter wheat followed chemical fallow after spring barley (treatment 9). High populations under winter pea likely reflected a residually high population from the previous crop of winter wheat.

It appears probable that elevated populations of root-lesion nematodes are occurring following winter wheat and the "summer-fallow winter" because of the functional monoculture for these winter wheat production systems; e.g., winter wheat is produced for 10 or 11 months of a 24-month cycle and volunteer wheat and winter-annual grass weeds (downy brome) are allowed to grow for up to 5 months during the 14-month summer-fallow phase of the rotation. Root-lesion nematodes are apparently being amplified during both phases of this functional monoculture, as compared to a more restricted period of living plants in annual spring wheat systems.

Spring barley continues to suppress populations of these nematodes. Specifically, root-lesion nematode populations tended to be lower in continuous barley than in the two treatments where spring or winter wheat was produced annually.

Grain yield

The 2005-2006 crop year was the third cropping season of this experiment. One more year is required to complete a full cycle for 2-year rotations and 3 more years are required to complete a full cycle for 3-year rotations. Grain yields of winter wheat, spring wheat, spring barley, and winter pea obtained in the 2005-2006 crop year are shown in Table 4. This crop year was much wetter (16.92 inches) than the 2004-2005 crop year (7.76 inches), resulting in higher yields. Continuous spring barley produced the highest yield but the spring barley yields were not significantly different from yield produced by winter wheat following conventional fallow or winter wheat after chemical fallow in a 3-year rotation with spring barley. The barley yield was, however, significantly higher than the yield of winter wheat after chemical fallow (2-year rotation). Yield from annual crops was significantly lower than yield of wheat following fallow or continuous spring barley. Continuous winter wheat produced the lowest yield. At first we suspected that downy brome, whose populations were highest in this treatment, competed with wheat for water and resulted in low wheat yields. However, soil moisture data showed that this treatment had more residual moisture than all cropped treatments, particularly in soil zones below 8 inches. This suggested that there were other factors that influenced yield of continuous winter wheat. High incidences of Fusarium crown rot lesions and root-lesion nematodes in this treatment could have reduced yields. Fertility could be another factor; downy brome, whose populations were high in this treatment, probably competed with wheat for nutrients.

Table 4. Grain yield of winter wheat, spring wheat, spring barley, and winter peas under different cropping systems at Columbia Basin Agricultural Research Center, Moro, Oregon, 2005.

Rotation	Grain yield (bu/acre)			
Annual cropping	2003-2004	2004-05	2005-06	2-yr avg
Continuous *winter wheat*	50.9ab	10.6c	18.4d	14.5de
Continuous *spring wheat*	39.4c	10.1c	37.7bc	23.9de
Continuous *spring barley*	54.3a	11.6c	63.6a	37.6bc
2-year rotations				
Conventional fallow-*Winter wheat*	48.1b	58.0a	58.6a	58.3a
Chemfallow-*Winter wheat*	48.8ab	52.9ab	45.9b	49.4ab
Winter wheat-*winter pea*		9.1c	17.1d	13.1e
Winter pea-*winter wheat*	48.5ab	40.5ab	32.8c	36.6c
3-year rotations				
Chemfallow-*winter wheat*-spring barley	50.1ab	63.2a	56.9a	60.1a
Winter wheat-*spring barley*-chemfallow	40.6c	12.8c	58.0a	35.4cd
Flex crop				
Spring barley-*spring wheat*	37.0c	12.9c	-	
Spring wheat-*spring barley*	41.8c	13.8bc	-	
Spring wheat-*mustard*	-	-	13.6d	
Precipitation (mm)	11.9	7.8	16.9	

†All plots are direct seeded except the conventional fallow treatments (rotation 1).

On average (2004-2005 and 2005-2006), wheat following fallow in a 3-year rotation with spring barley produced the highest yield, although this yield was not significantly different from yield of wheat after conventional or chemical fallow. Data on nematodes indicated that continuous spring barley suppressed nematodes. In rotations involving annual cropping, continuous spring barley produced the highest yields, followed by winter wheat after winter pea. Continuous winter wheat produced the lowest yields over the 2 crop years. The initial yields of the experiment (2003-2004 crop year) were not included in the averages because all crops followed spring wheat

Center of Sustainability, Heppner

Grain yield

Grain yields produced in the 2002-2003 to the 2005-2006 crop years are shown in Table 5. Results exclude 3-year rotations. Under continuous cropping, spring barley produced the highest yields followed by winter wheat. The average yields of continuous winter wheat do not reflect the true picture because the wheat was planted in an almost fallow situation following a 30 lb/acre lentil crop in the 2002-2003 crop year. Continuous spring wheat produced the lowest yields. Winter wheat after either conventional fallow or chemical fallow produced much higher yields than continuous crops but annualized yields were lower than continuous spring barley. The experiments will run for 3 more crop years for all rotations to complete a full cycle.

Table 5. Grain yield of winter wheat, spring wheat, and spring barley under different cropping systems at the Center of Sustainability, Heppner, Oregon.

	Continuous cropping				2-year rotations		
Rotation	3	4	5	6	1	2	Precip.
Year	Cont. S. Barley	Cont. S. Wheat	Cont. DNS	Cont. W. Wheat	W. Wheat after Conv. fallow	W. Wheat after Chem. fallow	Sept-June
	bu/acre						--- in ---
2002-2003	24	14	12	30 (Lentil)	19	25	10.6
2003-2004	47	32	33	42	44	46	11.6
2004-2005	42	16	23	25	68	71	9.4
2005-2006	52	29	28	34	47	56	14.5
Mean[1]	**47**	**26**	**28**	**34**	**53**	**58**	**11.9**
Annual	**47**	**26**	**28**	**34**	**27**	**29**	

[1] 2003-2004 to 2005-2006 crop-year mean.

Diseases

Nematode populations were evaluated in soil samples collected during 2005 and 2006 from treatments 112 (direct-drill hard red spring wheat [HRSW]), 113 (direct-drill soft white spring wheat [SWSW]), 114 (direct-drill spring barley [SB]), 115 (2005: conventional fallow in a rotation with soft white winter wheat [SWWW]; 2006: SWWW following fallow), 116 (2005: SWWW in a rotation with conventional fallow; 2006: fallow following SWWW), and 111 (2005: chemical fallow in a rotation with SWWW; 2006: SWWW following chem-fallow). Samples were collected with a Giddings hydraulic soil sampler (Giddings Machine Co., Windsor, CO). Five samples were collected for each of the six COS treatments. Each field sample was a composite of two cores taken 3 ft apart. Soil cores were separated into depth intervals of 0-6, 6-12, 12-18, 18-24, 24-36, and 36-48 inches. Root-lesion nematodes were extracted from the 180 samples; 6 treatments by 5 sites/treatment by 6 depth intervals/site. Populations for each depth increment were determined and averaged among the five sampling sites/plot.

For shallow samples (0 to 6 inches) approximating the depth sampled using small manually inserted soil probes, populations of *Pratylenchus neglectus* (root-lesion nematode) exceeded the economic threshold level in two of six COS treatments during 2005 and in five of six treatments sampled during 2006. During 2005, populations exceeded the economic threshold level of 900 *Pratylenchus*/lb of soil in treatments where SWWW was rotated with either conventional summer fallow or chemical summer fallow. Moderately high populations nearly equaling the economic threshold level were also detected in two direct-drill annual spring wheat treatments planted to either SWSW or HRSW (Dark Northern Spring (DNS)). During 2006, *P. neglectus* populations were less than half the economic threshold value in the annual spring barley treatment and exceeded the threshold in the other five treatments. The latter findings were identical to data bulked over the full 24-inch soil depth and combined over years 2005 and 2006; namely the population of *P. neglectus* in the spring barley treatment (498/lb of soil) was much lower than for annual HRSW (1,388/lb), annual SWSW (1,432/lb), SWWW/chem fallow (2,056/lb), and SWWW/conventional fallow (1,599/lb for in-crop phase and 1,680/lb for fallow phase).

During 2005 grain yield for direct-drill HRSW (cv 'Jefferson'; COS treatment no. 112) was 41 percent greater than for an adjacent treatment of direct-drill SWSW (cv 'Alpowa'; treatment no. 113). Mean populations of *P. neglectus* were near the estimated economic threshold level in both treatments. A nematicide experiment was therefore placed into the two COS treatments during 2006 to determine if root-lesion nematode could be responsible for the yield difference observed during 2005. Nematicide treatments consisted of Temik® (Bayer CropScience)-treated and untreated control plots replicated six times in the SWSW and HRSW plantings. Each plot measured 11 by 50 ft and consisted of either no treatment or application of Temik 15G before planting. The nematicide was drilled into soil at 3-inch depth and 25 lb/acre. During 2006, root-lesion nematode populations in both plantings were above the estimated threshold for causing economic damage. Grain yields differed between nematicide treatments (P = 0.017) but not between varieties (P = 0.177). Temik-treated plots averaged 1.6 bu/acre more than for untreated plots ($LSD_{0.05}$ = 1.3). The yields were 31.7 and 30.4 bu/acre for Temik-treated and untreated 'Alpowa', and 32.9 and 30.9 bu/acre for Temik-treated and untreated 'Jefferson'. We concluded that *P. neglectus* suppressed yields of both varieties equally during 2006 and were unlikely to have been responsible for the strong yield differential between varieties during 2005. It was of interest, however, that depth profile samples averaged over both years indicated that *P. neglectus* populations at the 12- to 24-inch depth increment were more than twice as high for the 'Alpowa' than 'Jefferson' treatment, and that the opposite relationship occurred in the 0- to 12-inch depth increment. Crop-year precipitation was 9.4 inches during 2005 and 14.5 inches during 2006 (Table 5). It is possible that the higher population of *P. neglectus* deep in the soil profile under 'Alpowa', as compared to 'Jefferson', may have imposed a higher level of drought stress on

‘Alpowa’ than ‘Jefferson’ during the drier (2005) but not the wetter year (2006), leading to a yield difference for these varieties during 2005 but not 2006 (Table 5).

References

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Precipitation Summary - Pendleton

CBARC - Pendleton Station - Pendleton, Oregon
(Crop year basis, i.e.; September 1 through August 31 of following year)

Crop Yr.	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total
77 Year Average	**.72**	**1.37**	**2.07**	**2.05**	**1.97**	**1.52**	**1.73**	**1.55**	**1.51**	**1.23**	**.33**	**.46**	**16.50**
1986-87	1.87	.91	3.41	.95	2.08	1.31	1.85	.83	1.63	.62	.47	.06	15.99
1987-88	.04	0	1.44	1.61	2.60	.32	1.65	2.59	1.79	.94	0	0	12.98
1988-89	.40	.08	3.65	1.10	2.86	1.55	2.95	1.94	2.19	.33	.15	1.19	18.39
1989-90	.24	1.00	1.65	.49	1.43	.63	1.89	1.77	2.14	.70	.37	.76	13.07
1990-91	0	1.37	1.73	1.18	1.15	.86	1.71	1.01	4.73	2.22	.15	.24	16.35
1991-92	.03	.89	4.18	.97	.96	1.34	.85	1.29	.20	.90	1.74	.78	14.13
1992-93	.58	1.70	2.61	1.30	2.43	1.04	2.32	2.67	1.58	2.01	.47	2.60	21.31
1993-94	0	.30	.49	1.91	2.38	1.67	.52	1.18	2.88	.75	.33	.07	12.48
1994-95	.76	1.44	3.77	1.83	2.75	1.15	2.35	2.92	1.56	1.73	.22	.41	20.89
1995-96	.93	1.35	2.95	2.37	2.79	2.45	1.49	2.33	2.00	.39	0	.05	19.10
1996-97	.66	1.99	3.05	4.23	2.74	1.60	3.00	2.46	.46	1.10	.36	.02	21.67
1997-98	.88	1.34	1.59	1.41	2.84	.87	1.43	1.30	3.12	..51	.18	.10	15.57
1998-99	1.24	.40	4.71	2.96	1.18	2.16	1.23	.99	1.65	.61	.04	1.18	18.35
1999-00	0	1.75	2.17	1.88	2.39	3.35	3.39	.65	1.98	1.39	.31	0	19.26
2000-01	1.75	3.84	1.61	.84	1.29	.89	1.42	2.13	.75	1.47	.55	0	16.54
2001-02	.36	1.91	1.88	1.02	1.36	1.33	1.41	1.12	1.02	1.39	.23	0	13.03
2002-03	.24	.61	1.09	3.06	3.25	2.18	2.20	1.78	1.01	0	0	.23	15.65
2003-04	.70	.68	1.68	3.33	2.77	2.29	.85	2.03	2.78	1.88	.12	.91	20.02
2004-05	.54	.75	2.09	1.08	.53	.33	1.76	1.41	2.80	.66	.19	.01	12.15
2005-06	.06	1.37	1.64	2.14	3.45	1.00	2.50	2.84	1.57	2.18	.11	0	18.86
2006-07	.73	.84	3.53	2.31	.64	1.76	1.64	1.10					
20 Year Average	**.56**	**1.18**	**2.37**	**1.78**	**2.16**	**1.42**	**1.84**	**1.76**	**1.89**	**1.09**	**.30**	**.43**	**16.79**

Precipitation Summary - Moro

CBARC - Sherman Station - Moro, Oregon
(Crop year basis, i.e.; September 1 through August 31 of following year)

Crop Yr.	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total
97 Year Average	**.56**	**.92**	**1.69**	**1.67**	**1.61**	**1.15**	**.96**	**.80**	**.85**	**.68**	**.22**	**.28**	**11.38**
1986-87	1.52	.45	1.53	.78	1.68	1.10	1.54	.28	.99	.29	.78	.11	11.05
1987-88	.07	.01	.66	3.23	1.60	.21	1.25	2.21	.55	1.02	.04	0	10.85
1988-89	.56	.02	2.51	.22	1.33	.77	1.91	.84	.91	.08	.11	.50	9.76
1989-90	.07	.59	.96	.48	1.91	.17	.76	.79	1.36	.39	.15	1.43	9.06
1990-91	.29	1.27	.61	.74	.87	.60	1.43	.40	.77	1.27	.33	.16	8.74
1991-92	0	1.40	2.57	1.02	.47	1.64	.64	2.38	.04	.28	.81	.02	11.27
1992-93	.68	.85	1.50	1.68	1.42	1.47	1.68	1.22	1.42	.87	.39	.30	13.48
1993-94	.02	.09	.41	.68	1.40	.90	.55	.40	.62	.61	.11	.07	5.86
1994-95	.19	2.27	1.79	.90	3.67	1.18	1.14	1.95	.97	1.45	1.10	.17	16.78
1995-96	1.02	.64	3.20	2.20	1.86	2.43	.65	1.57	1.44	.36	.15	.03	15.55
1996-97	.55	1.56	2.63	4.18	1.57	.84	1.28	1.26	.55	.56	.13	.57	15.68
1997-98	.46	1.61	.66	.29	2.49	1.30	1.02	.66	3.15	.26	.26	.06	12.22
1998-99	.38	.16	2.57	1.34	1.34	1.00	.51	.06	.56	.11	.09	.23	8.35
1999-00	0	.83	1.62	.62	1.77	2.43	.76	.44	.48	.20	0	0	9.15
2000-01	.30	1.39	.60	.35	.43	.53	.81	.71	.34	.50	.02	.23	6.21
2001-02	.53	1.03	2.02	1.17	.68	.65	.42	.38	.66	.85	.04	0	8.43
2002-03	.02	.27	.59	2.65	1.92	1.26	.90	1.00	.21	0	0	.47	9.29
2003-04	.25	.65	.73	2.44	1.58	1.47	.61	.79	.93	1.11	.29	1.06	11.91
2004-05	.47	.79	.32	1.55	.42	.12	.77	.75	2.44	.13	.12	0	7.88
2005-06	.05	1.81	1.88	3.65	2.67	1.05	.63	1.80	1.83	1.49	.06	.02	16.94
2006-07	.02	.77	3.17	2.51	.84	.78	.66	.93					
20 Year Average	**.37**	**.88**	**1.47**	**1.51**	**1.55**	**1.06**	**.96**	**.99**	**1.01**	**.59**	**.25**	**.27**	**10.92**

Average Maximum Temperature Summary - Pendleton

CBARC - Pendleton Station - Pendleton, Oregon
(Crop year basis, i.e.; September 1 through August 31 of following year)

Crop Yr.	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	MAX
77 Year Average	**78**	**65**	**49**	**42**	**40**	**46**	**54**	**62**	**71**	**79**	**89**	**88**	**115**
1986-87	72	68	49	37	38	47	56	68	74	82	85	87	104
1987-88	83	72	52	41	40	50	56	64	69	77	90	88	102
1988-89	79	74	52	41	45	33	52	64	69	81	88	83	101
1989-90	80	65	54	40	44	46	57	68	68	78	92	87	108
1990-91	85	64	55	35	40	55	52	62	66	73	89	91	100
1991-92	82	67	48	43	44	51	59	65	76	86	86	89	104
1992-93	76	67	46	40	33	36	50	61	74	76	79	83	98
1993-94	81	68	46	41	49	42	58	65	72	78	92	88	107
1994-95	82	63	46	43	41	52	55	60	70	75	88	84	98
1995-96	81	63	54	40	43	42	52	63	65	78	92	89	107
1996-97	75	64	48	44	41	45	55	60	74	77	86	90	102
1997-98	79	65	50	41	47	53	55	61	67	78	95	92	111
1998-99	83	66	53	44	50	51	55	61	68	78	88	89	103
1999-00	80	66	56	45	42	47	53	67	70	78	88	89	105
2000-01	75	63	44	38	39	44	58	60	75	77	87	91	102
2001-02	83	65	52	44	46	51	49	62	69	81	93	86	110
2002-03	80	64	52	45	46	49	58	61	70	84	94	90	107
2003-04	83	71	49	44	34	48	61	66	67	78	91	89	103
2004-05	77	67	53	47	44	51	61	64	71	77	91	90	102
2005-06	78	67	48	39	53	47	54	62	72	79	87	82	104
2006-07	79	64	52	40	39	47	59	61					97
20 Year Average	**79**	**66**	**50**	**41**	**42**	**47**	**56**	**63**	**70**	**79**	**89**	**89**	**111**

Average Minimum Temperature Summary - Pendleton

CBARC - Pendleton Station - Pendleton, Oregon
(Crop year basis, i.e.; September 1 through August 31 of following year)

Crop Yr.	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	MIN
77 Year Average	**43**	**35**	**31**	**27**	**24**	**28**	**32**	**36**	**42**	**47**	**51**	**50**	**-30**
1986-87	42	34	35	27	21	31	35	38	44	47	52	47	-3
1987-88	43	29	32	25	24	26	31	39	42	48	51	47	3
1988-89	42	39	35	27	28	15	33	39	42	48	49	52	-18
1989-90	41	35	34	26	31	26	31	38	42	49	54	53	-4
1990-91	45	36	35	14	23	34	31	36	42	46	51	53	-26
1991-92	42	33	34	30	33	34	32	39	41	51	53	52	11
1992-93	43	37	34	24	16	21	31	38	47	49	51	50	-12
1993-94	42	37	19	30	32	26	32	40	45	47	53	51	-4
1994-95	44	34	32	28	28	31	32	36	42	47	54	47	-5
1995-96	47	36	36	29	27	22	33	38	41	45	53	51	-21
1996-97	42	37	31	28	24	30	35	36	44	48	51	53	-3
1997-98	47	35	34	28	29	33	33	35	43	48	57	52	3
1998-99	49	33	36	26	32	32	33	32	39	47	49	54	-5
1999-00	38	32	36	32	29	32	31	37	44	46	51	48	19
2000-01	45	37	27	27	28	27	32	36	42	47	52	52	16
2001-02	45	34	34	28	28	29	30	34	40	50	54	48	18
2002-03	42	29	30	32	34	29	37	37	43	47	53	51	9
2003-04	46	40	26	29	21	30	34	35	43	48	52	55	-20
2004-05	44	38	31	30	26	22	32	36	45	45	52	49	11
2005-06	39	37	31	24	34	25	33	36	40	49	57	52	3
2006-07	44	33	33	26	23	30	33	34					3
20 Year Average	**43**	**35**	**32**	**27**	**27**	**28**	**33**	**37**	**42**	**48**	**52**	**51**	**-26**

Average Maximum Temperature Summary - Moro

CBARC - Sherman Station - Moro, Oregon
(Crop year basis, i.e.; September 1 through August 31 of following year)

Crop Yr.	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	MAX
77 Year Average	**75**	**62**	**47**	**39**	**37**	**43**	**51**	**59**	**67**	**74**	**83**	**82**	**111**
1985-86	66	59	33	24	39	43	55	56	67	80	75	87	101
1986-87	67	65	48	34	36	44	51	63	70	78	78	82	98
1987-88	78	68	49	36	35	47	52	59	63	70	83	81	100
1988-89	74	71	49	39	44	32	48	62	66	76	78	77	99
1989-90	76	61	51	40	43	45	54	63	64	73	87	82	106
1990-91	80	60	52	34	39	51	49	58	62	68	83	86	98
1991-92	78	64	46	40	43	48	57	61	72	81	82	84	103
1992-93	71	62	46	37	30	35	47	57	71	71	73	80	95
1993-94	78	66	45	38	48	41	57	62	69	73	88	82	106
1994-95	80	62	45	42	37	49	52	57	68	71	81	78	96
1995-96	78	61	53	38	42	40	50	59	61	73	88	84	103
1996-97	72	61	47	42	40	45	53	57	71	73	80	85	99
1997-98	76	61	49	41	42	47	52	58	63	73	88	85	106
1998-99	81	62	50	41	47	48	52	57	64	71	81	83	100
1999-00	76	62	51	42	37	42	51	62	64	74	80	81	97
2000-01	72	60	41	36	36	42	54	57	71	72	81	85	100
2001-02	78	61	49	40	42	47	48	58	65	76	84	81	104
2002-03	76	61	49	40	43	47	56	57	66	78	88	84	102
2003-04	78	67	44	38	33	43	57	63	67	77	85	84	100
2004-05	72	63	51	44	40	48	57	59	50	72	85	86	100
2005-06	73	62	45	35	45	44	50	59	68	75	87	82	104
2006-07	77	63	47	37	38	45	55	57					95
20 Year Average	**75**	**63**	**48**	**39**	**40**	**44**	**52**	**59**	**66**	**74**	**83**	**83**	**106**

Average Minimum Temperature Summary - Moro

CBARC - Sherman Station - Moro, Oregon
(Crop year basis, i.e.; September 1 through August 31 of following year)

Crop Yr.	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	MIN
77 Year Average	**46**	**38**	**31**	**27**	**24**	**28**	**32**	**36**	**42**	**48**	**54**	**53**	**-24**
1986-87	44	39	34	25	23	31	34	40	46	50	54	52	7
1987-88	49	38	32	25	25	29	33	39	41	48	52	50	4
1988-89	45	42	34	27	29	16	31	38	43	49	53	53	-15
1989-90	46	37	34	26	31	26	32	39	41	48	56	55	13
1990-91	49	37	35	17	22	33	30	36	41	46	54	56	-16
1991-92	47	37	33	30	31	35	35	40	45	53	55	54	12
1992-93	45	39	33	22	17	20	31	36	46	49	50	51	-3
1993-94	46	40	22	28	32	25	33	39	45	48	56	54	-3
1994-95	48	36	30	28	25	32	31	36	45	49	55	50	-2
1995-96	49	38	36	28	27	23	32	37	40	47	55	52	-15
1996-97	44	38	31	27	26	29	34	36	45	48	53	56	7
1997-98	49	38	33	28	27	32	33	36	43	48	57	54	2
1998-99	50	34	35	25	30	30	30	34	39	47	51	56	-2
1999-00	44	35	35	30	25	29	33	38	42	46	52	52	13
2000-01	52	38	27	25	26	26	32	35	43	47	54	56	10
2001-02	49	36	33	29	29	28	29	35	41	51	55	51	3
2002-03	45	33	27	33	33	29	35	35	42	50	57	56	7
2003-04	49	42	27	28	22	29	36	37	44	49	56	58	-6
2004-05	47	40	31	29	25	26	33	36	45	45	52	54	6
2005-06	45	39	29	22	32	25	31	36	43	50	57	52	6
2006-07	45	37	31	24	23	30	34	35					4
20 Year Average	**47**	**38**	**32**	**27**	**27**	**28**	**32**	**37**	**43**	**48**	**54**	**54**	**-16**