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Oregon State University

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2009 Dryland Agricultural Research Annual Report

Cooperating Research Units

Columbia Basin Agricultural Research Center
Oregon State University

Columbia Plateau Conservation Research Center
USDA-Agricultural Research Service

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INTRODUCTION

Staffs of the Columbia Basin Agricultural Research Center (CBARC, Oregon State Univer-sity [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 and USDA-ARS website http://ars.usda.gov/pwa/cpcrc. Past issues are also available through the local county extension office. Changes in staffing, programming, and facilities at these centers during the past year are summarized below.

Promotions and Awards

ARS: Within ARS, those receiving performance awards were Wayne Polumsky, Richard Greenwalt, Bob Correa, Patrick Scharf, Jean Wise, Pat Frank, and John Williams. The Umatilla Soil and Water Conservation District awarded John Williams a Distinguished Service Certificate for his participation and contributions to the District.

CBARC: Dan Ball served as President of the Western Society of Weed Science; Stephen Machado was elected Division Chair of A-11, Biometry, of the American Society of Agronomy; Steve Petrie is the Board Representative from A-7, Experiment Station Administration, of the American Society of Agronomy as well as Chair of the Budget and Finance Committee; and Don Wysocki was Vice President of the Soil and Water Conservation Society.

Staff Changes

ARS: New for 2008 were: Maylene Bustard, Office Automation Clerk trainee. Leaving ARS were Amy Baker and Judy Skjelstad.

Summer workers were Charles Martin, Byron Morris, Roxanne Cannon, Stefka Waite, and Stephanie Machado. Bryon Morris was hired through the student summer internship program administered by the Confederated Tribes of the Umatilla Indian Reservation. Jan Eitel, graduate student with College of Natural Resources, University of Idaho, completed his remote sensing research project with Dan Long and was awarded the Ph.D. degree.

CBARC: Jason Sheedy resigned in January, 2008 and returned to Australia and Sandra Easley resigned in February, 2008. Alison Thompson resigned in August, 2008 to pursue her Ph.D. under the direction of Dr. Kim Campbell, USDA-ARS wheat geneticist at Pullman, Washington. Dick Smiley will serve on her committee. Mr. Hui Yan worked in the plant pathology program for six months during 2008 after earning the M.S. degree in Statistics at the University of Idaho. His duties included assisting with statistical analyses of on-going research projects, with development of technical publications to report results of that research, and with all aspects of greenhouse and laboratory research with cereal cyst and root-lesion nematodes

Summer workers were Wendy Baker, Sam Busskohl, John Campbell, Jason Clark, Araceli Contreras, Korey Dallman, Chase Endicott, Shannon Goff, Marc Gushwa, John Huntsman, David Imhoff, Michael Imhoff, Fatima Machado, Stephanie Machado, Lindsey McCoy, Katie McCune, Jessica Merriman, Amanda Rinehart, and Tod Sharrard.

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New Projects and Grants Received

OSU: Scientists and Extension specialists at CBARC continue to be quite successful at writing proposals for external grants and contracts. The total value of external grants received in 2008 was $643,000; the three-year average of external grants is $610,000. Grant sources include regional competitive grant programs such as STEEP III and the Grass Seed Cropping Systems for Sustainable Agriculture; commodity commissions such as the Oregon Wheat Commission and the Columbia Basin Grass Seed Association; and private industry.

Dr. Dick Smiley continued as a member of Grant Poole's Ph.D. dissertation committee at WSU. This Ph.D. work is a direct outgrowth of the work on Fusarium that Dr. Smiley has conducted during the last 15 years. It utilizes pathogen cultures and varieties identified and conserved by his program at Pendleton. Dick is also a member of the Ph.D. committee for Alison Thompson who is continuing the work in which she was engaged while working at CBARC. Her dissertation research aims to identify genetic markers for root-lesion nematode resistance genes crossed into PNW wheat varieties while working at CBARC, to identify additional sources of genetic resistance in Iranian landrace lines, to determine the mechanism(s) enabling the resistance genes to inhibit nematode reproduction, and to utilize molecular procedures developed at CBARC to determine the geographic distribution of lesion nematode species in Washington.

ARS: Scientists with WSU Center for Precision Agricultural Systems, ARS-Prosser, and ARS-CPCRC received $300,000 from the USDA-CSREES National Research Initiative (subcontracted portion to ARS-CPCRC is $69,200) for a three-year project entitled "Biomass production: Effects of net primary productivity and residue removal on soil carbon and nitrogen transformation".

Facilities and Equipment

OSU:

- Design and fabricate small plot no-till drill in cooperation with Jim Peterson
- Repair and upgrade corn planter for the Sherman Station
- Recondition 8-ft flail mower
- Repair to water main
- Install data logger on Weedseeker sprayer
- Demolition of abandoned chimney in headhouse
- Renovation of lawn and establishment of drought tolerant grasses

ARS:

- A slightly used, narrow Kubota model 8450 tractor was purchased and fitted with a Rears flail for forage harvesting in biofuels research.
- A new Holland Scientific model 470, 3-band active crop canopy sensor was purchased with grant funds to support remote sensing research.
- The metal storage area, comprising the four bays on the north end of the machine shop, was reorganized as the designated area for welding and metal fabrication. Energy saving T-8 lighting was installed.
- The high-wheeled Spra-Coupe was modified for rear-mounting of the Giddings hydraulic soil probe. This vehicle can now be used for soil sampling in an experiment with switchgrass and annual crops without disturbing the plots with wheel traffic.
- A large, obsolete satellite dish was removed from the roof of the main building.
- Repaired water damage to ceiling and walls of Room 109 and associated hallway. Replaced air relief valves with ball shut-off valves to prevent reoccurrence of this problem.
- A new, commercial-grade expansion tank for the heating system was installed.
- Three solar powered, 200-W power units were purchased for supplying electricity to sensors that continuously measure CO_2, O_2, soil moisture content, and soil temperature in an experiment with switchgrass.
- Cracks in the asphalt parking lot were sealed with hot rubberized sealant.
- A new heater was placed in the well house to prevent freezing during winter.
- The air handling unit in the main building was repaired.
- Two heat pumps were replaced that provide air conditioning to the annex building.
- Nine overhead garage bay doors of the machine shop were resealed and insulated.

Training

All OSU and ARS employees licensed to apply pesticides and herbicides 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, cardiopulmonary resuscitation (CPR), and automatic external defibrillator (AED) training.

Outreach

OSU scientists and Extension specialists made 68 presentations at grower meetings organized by Extension agents and private industry, regulatory and advisory agency meetings, outdoor workshops, soil judging contests, and others. They also organized 6 professional meetings. CBARC scientists and Extension specialists authored 7 refereed Extension publications and were co-authors on 6 more. They also have a total of 12 reports on “Oregon Invests!”. In addition, OSU faculty members were authors or co-authors on 16 articles in refereed journals.

Stewart Wuest visited Pendleton High School to discuss scientific experiments with the Advanced Biology classes. Katherine Skirvin, Tami Johlke, and Pat Frank were presenters for ARS at the Umatilla-Morrow Education Service District's annual Career Showcase at the Pendleton Convention Center. ARS scientists and technicians taught a unit on "Soil as a Precious Natural Resource" at Sunridge Middle School's Outdoor School. Stewart Wuest and John Williams served as judges for the restart of the annual Pendleton High School Science Fair.

Visitors

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

- Ed van Ouwerkerk, Assistant Scientist and Software Developer, Agricultural and Biosystem Engineering, Iowa State University, Ames, IA.
- David J. Muth, Research Engineer, Biofuel and Renewable Energy Technology, Idaho National Laboratory, Idaho Falls, ID.
- E. Raymond Hunt Jr., Research Physical Scientist, USDA-ARS, Hydrology and Remote Sensing Laboratory, Beltsville, MD.
- Jeffrey J. Steiner, National Program Leader, USDA-ARS National Program Staff, Beltsville, MD.
- Tana Simpson, Administrator, Oregon Wheat Commission, Portland, OR.
- Chris Rauch, Chairman, Oregon Wheat Commission, Morrow County, Lexington, OR.
- Sherman Reese, Vice Chairman, Oregon Wheat Commission, Umatilla County, Echo, OR.
- Tom McCoy, Commissioner, Oregon Wheat Commission, Wasco, OR.
- Daren Coppock, Chief Executive Officer, National Association of Wheat Growers, Washington D.C.
- Bill White, Leader-Programs, USDA-NRCS, State Office, Portland, OR.
- Jay Gibbs, John Day/Umatilla Area Basin Team Leader, USDA-NRCS, Heppner, OR.
- Ron Alvarado, State Conservationist, USDA-NRCS, State Office, Portland, OR.
- Umakant Mishra, Graduate Research Associate, School of Environment and Natural Resources, The Ohio State University, Columbus, OH.
- Clinton Reeder, economist and farmer, Adams, OR.

Seminars

- Ed van Ouwerkerk, software developer, I-Farm whole farm model and decision tool demonstration, Agricultural and Biosystem Engineering, Iowa State University, Ames, IA.
- E. Raymond Hunt Jr., New applications of remote sensing for agriculture. Hydrology and Remote Sensing Laboratory, Beltsville, MD.
- Umakant Mishra, Geographic weighted regression and regression kriging in predicting soil organic carbon at a regional scale, The Ohio State University, Columbus, OH
- Clinton Reeder, Fossil fuel products and their effects on agricultural sustainability and other issues from an eastern Oregon perspective, Adams, OR.

Liaison Committees

Chairpersons Jerry Zahl and Ernie Moore led the Pendleton and Sherman Liaison Committees, respectively. 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. Stan Timmermann is the chair of the Pendleton Station Endowment Fund Committee and has taken an active role in fundraising for the station.

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. 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 Bev Kopperud of the Umatilla Soil and Water Conservation District and the Board of Directors of Oregon Wheat Growers League: Tammy Dennee, Kevin Porter, Jeff Newtson, Darren Padgett, and Craig Reeder.

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, Inc.
BASF Corp.
Bayer CropScience Seed Treatment
BMCC
Dupont Agricultural Products
Farm Credit Service
Farm Equipment Headquarters, Inc.
Inland Chemical Service, Inc.
The McGregor Co.
Main Street Cowboys
Mid-Columbia Bus Co.
Oregon Wheat Commission
Oregon Wheat Growers League
Pendleton Flour Mills
Pendleton Grain Growers, Inc.
RDO Equipment Co.
Smith Frozen Foods, Inc.
Walla Walla Farmers Cooperative
Wheatland Insurance
Wilbur-Ellis Co.

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
Bayer CropScience
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
RDO Equipment
Richelderfer Air Service
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 and 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.

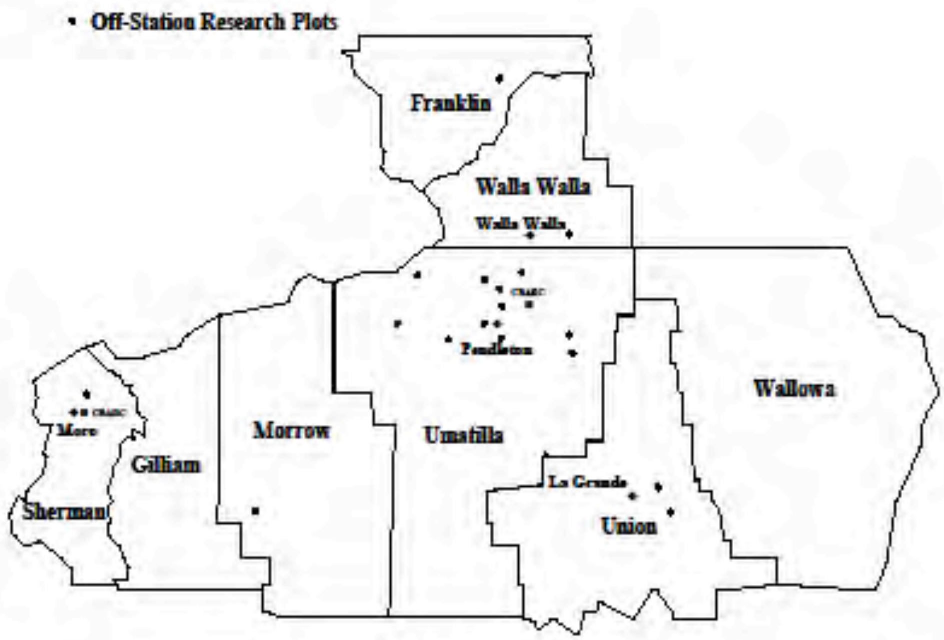
Steve Petrie
Superintendent
OSU-CBARC

Dan Long
Research Leader
USDA-ARS-CPCRC

RESEARCH PLOT LOCATIONS

Eastern Oregon - Eastern Washington

Counties



FRANKLIN, WA
Paul Herrman

MORROW, OR
Bill Jepsen

SHERMAN, OR
Doug Bish
Bryan Cranston
Daryl Hart
Tom McCog
Bryan Peters
Dan Richelder
Nate Smith
Ray Smith

UMATILLA, OR
Bracher Farms
•Cliff Bracher
•Judy Bracher
•Paul Bracher
•Randy Bracher
Cunningham Sheep Co.
Jim Duff
Bill Gentry
Mark Kirsch
Bill Lorenzen
Eric Nelson
Clinton Reeder
Leon Reese
Sherman Reese
Bob Roselle
Pat Straughn
Dean Windham

UNION, OR
Mark DeLint
Colton Rasmussen

WALLA WALLA, WA
Dwellie Jones

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Molecular Identification of Cyst Nematodes from Wheat and Barley Fields

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Abstract

Cyst nematodes (*Heterodera* spp.) are important plant-parasitic nematodes in fields of the Pacific Northwest (PNW). To monitor population density and to disclose diversity and distribution of cyst nematode species in the PNW, soil samples were collected from infested wheat and barley fields in Oregon, Washington, and Idaho, and polymerase chain reaction (PCR) and restriction fragment-length polymorphism (RFLP) were used to identify the nematode species. Soil samples collected at 100-ft intervals in the same Union County field where the cereal cyst nematode *H. filipjevi* was first reported in Oregon revealed that *H. filipjevi* was present in most of the infested sampling sites, that some sites contained no cyst nematodes, and that mixtures of *H. avenae* and *H. filipjevi* occurred at several other sampling sites within that field. All cyst nematodes in soils collected from surrounding areas in Union County were identified as *H. avenae*. Nematode extraction and quantification from soil also revealed high population densities of *H. avenae* in fields sampled near Palouse, Washington and St. Anthony, Idaho. Cysts from soil under a barley crop in an irrigated field near Paul, Idaho were determined to be *H. schachtii*. Intraspecific variation was not observed within *H. filipjevi* populations or within populations of *H. avenae* from Idaho, Oregon, and Washington. However, intraspecific variation was observed between *H. avenae* populations occurring in the PNW and France, based on evaluations of the conserved domain (ITS region) of the DNA sequences. Accurate identification of cyst nematode species and awareness of high population density in affected fields is essential for designing effective control measures.

Keywords: Cyst nematodes, *Heterodera filipjevi*, *H. avenae*, *H. schachtii*, molecular identification, population density, PCR-RFLP

Introduction

Cyst-forming nematodes (*Heterodera* spp.) are economically important soil-borne parasites that attack many agricultural crops worldwide. Currently, the genus *Heterodera* contains more than 60 species. These species belong to several taxonomic groups including the *H. avenae* group and *H. schachtii* group (Madani et al. 2004).

The cereal cyst nematodes (CCN; *H. avenae* group) contain at least 12 species that affect roots of cereals and grasses. Three main species (*H. avenae*, *H. filipjevi*, and *H. latipons*) are among the most economically important cyst nematode pests to cereals. *H. avenae* was first reported in the United States in 1974 and is now known to occur in at least seven western states including Oregon, Idaho, and Washington (Smiley et al. 2005, 2007). Wheat yields were negatively correlated with pre-plant densities of *H. avenae*. High populations of this species in commercial fields reduced winter wheat yields as much as 50 percent and occasionally destroyed recropped spring wheat in Union County, Oregon (Smiley et al. 1994, 2007). *H. filipjevi* was first reported in the United States in February 2008 (Smiley et al. 2008, Yan et al. 2008a). This plant-parasitic species was found in a winter wheat field in Union County, Oregon; the field contained large patches of stunted plants with up to 90 percent plant mortality. *H. filipjevi* is closely related to *H. avenae* and causes extensive damage to wheat, barley, oat, and other cereal and grass species elsewhere in the world (Smiley and Nicol 2009). *H. filipjevi* may cause significant damage to cereals in the United States if it is more widely spread and is present in fields at higher populations. Discovery of *H. filipjevi* in Oregon complicates cereal cyst detection and management strategies.

The beet cyst nematode, *H. schachtii*, is a major pest affecting sugar beet. *H. schachtii* belongs to the *H. schachtii* group that contains at least nine species. This nematode has been found in most beet growing areas in the United States. In Idaho and Oregon, the beet cyst nematode is one of the most serious limiting factors for sugar beet production (Hafez et al. 1992).

Within each *Heterodera* group, differentiation among the species is based on only minor morphological differences. Identification is thus time-consuming, requires great skill and training by the observer, and is frequently inconclusive because individual specimens often vary greatly within a population. Microscopic identification of *H. filipjevi* and *H. avenae* is not offered as a service by any commercial soil testing lab in the PNW. However, accurate identification of *Heterodera* spp. is needed as an initial step in designing appropriate management strategies. This is especially important when screening for possible sources of host resistance against *Heterodera* species.

Molecular techniques offer new possibilities for identifying species of plant-parasitic nematodes to an extent that could not be achieved with microscopic identification. Polymerase chain reaction (PCR) and restriction fragment length polymorphism (RFLP) have been used to distinguish these species (Bekal et al. 1997, Subbotin et al. 1999, Rivoal et al. 2003, Madani et al. 2004, Abidou et al. 2005, Yan et al. 2008a). Comparisons of PCR-RFLP profiles facilitate reliable identification of most species of cyst nematodes.

PCR-RFLP procedures require two steps. The first step uses PCR to amplify a region of DNA sequences and produce a fragment that does not show any difference between species. The second step uses a restriction enzyme to digest the PCR fragment, revealing a level of molecular polymorphism useful for differentiating species.

The objectives of this study were to (1) survey and collect cyst nematodes from infested wheat and barley fields in the PNW, (2) investigate population densities of cyst nematodes and their distribution, (3) employ PCR-RFLP to identify cyst nematodes to species level, and (4) examine possible intraspecific variation within *H. avenae* or *H. filipjevi* populations based on a conserved region of DNA sequences.

Materials and Methods

Soil sample collection and nematode preparation

Grid soil sampling was conducted in the same Imbler, Oregon field where *H. filipjevi* was first reported (Smiley et al. 2008). A grid of 100 ft was used to examine the uniformity of *H. filipjevi* distribution. A total of 50 soil samples (Fig. 1) was collected on April 17, 2008. Each sample consisted of 10-15 cores (1 inch diam by 12 inches deep) within a 3-ft radius. Nine soil samples were also collected from other fields at the same farm. Samples were stored at cold room (40^{o}F) temperature. Nematodes were extracted from approximately 0.44 lb of soil using the Whitehead tray method (Whitehead and Hemming 1965). Juvenile nematodes in the extracted suspensions were identified and quantified on a nematode counting slide under a microscope and converted to the number per lb of soil.

Soil samples were also collected from other wheat and barley fields or fields with recent wheat rotation history. These locations included farms near Imbler, Island City, and Union, Oregon; Paul and St. Anthony, Idaho; and Palouse, Washington (Table 1). Approximately 2-lb subsamples were sent to Western Laboratories (Parma, Idaho) for nematode microscopic identification (genus level) and quantification. The number of cyst nematode eggs and juveniles in 1 lb of soil were reported as population density. Cysts were extracted from another 0.44-lb subsample of soils and roots by the routine method of sieving-decanting. Extracted cysts were hand-picked with a dissecting needle under a stereomicroscope. Cysts were stored in distilled water at 40^{o}F and used for molecular identification.

DNA extraction

Three methods were used for cyst nematode DNA extraction. For the samples with gravid (egg-bearing) cysts, three to five cysts were used per DNA extraction. The cysts were cut open and the eggs and juveniles crushed between two glass slides under a dissecting microscope. The nematode suspension was then pipetted and used to isolate DNA, either by using a commercial kit (FastDNA® Kit, Bio 101, La Jolla, CA) according to the protocol recommended by the manufacturer, or the procedure as described by Rivoal et al. (2003). For the soil samples with empty cysts, juveniles were extracted from the soils by the Whitehead tray method and were used for DNA extraction. Twenty-four juveniles were hand-picked using a dental pick, placed in sterilized pure water on a concave glass slide, and cut into two pieces under a dissecting microscope. DNA was extracted using the protocol described by Waeyenberge et al. (2000), with some modifications. The DNA solution was stored at -4^{o}F and then was used for PCR amplification.

DNA of *H. avenae* (IB), *H. filipjevi* (E88), *H. latipons* (E99), and *H. schachtii* were acquired from cooperators in France and used as positive controls for purposes of identification. A no-DNA template was used as a negative control.

PCR-RFLP procedure

DNA was amplified using PCR with the *Heterodera*-specific primers (18S and 26S) as described by Vrain et al. (1992). PCR amplification was performed in a DNA thermal cycler (MyCycler™, Bio-Rad, Richmond, CA) using optimized procedures. Quality of PCR products was examined on agarose gels by electrophoresis. Restriction fragment length polymorphism (RFLP) was performed to identify the species of *Heterodera* (Bekal et al. 1997, Subbotin et al. 1999, Rivoal et al. 2003). Six restriction enzymes (*Taq*I *Hinf*I, *Pst*I, *Hae*III , *Rsa*I, and *Alu*I; Roche, Mannheim, Germany) were used to digest the PCR products at optimum incubation temperatures as recommended by the manufacturer. The DNA fragments were separated by size in agarose gels, detected on a UV-imaging system, photographed using a digital camera, and analyzed by a computer program (Polaroid PhotoMAX Pro™, Polaroid Corporation). The length of each fragment was estimated by a 100-base-pair (bp) DNA ladder (Roche, Mannheim, Germany). The species of *Heterodera* was identified by comparing the banding pattern with those of the control species.

Results and Discussion

Grid soil sampling revealed that cyst nematodes were unevenly distributed in the winter wheat field where *H. filipjevi* was discovered near Imbler (Union County) Oregon. The cyst nematode distribution pattern is shown in Figure 1. Of 50 sampling sites, 35 sites contained no cyst nematodes. Of 15 sites infested with the cyst nematodes, 10 sites had population densities less than 250 juveniles/lb of soil and 3 sites contained more than 400 juveniles/lb of soil. One site contained more than 1,000 juveniles/lb of soil. Populations greater than 100 juveniles/lb are likely to reduce wheat yield, particularly when combined with other stress factors such as diminishing supply of water or plant nutrition late in the growing season. We recommended that the grower rotate the field into a broadleaf crop because crops other than cereals and grasses will reduce the population of cereal cyst nematodes and improve yields of subsequent wheat crops. Uneven distributions of nematodes in fields have also been reported for root-knot nematodes (Qiu et al. 2006) and root-lesion nematodes (Yan et al. 2008b).

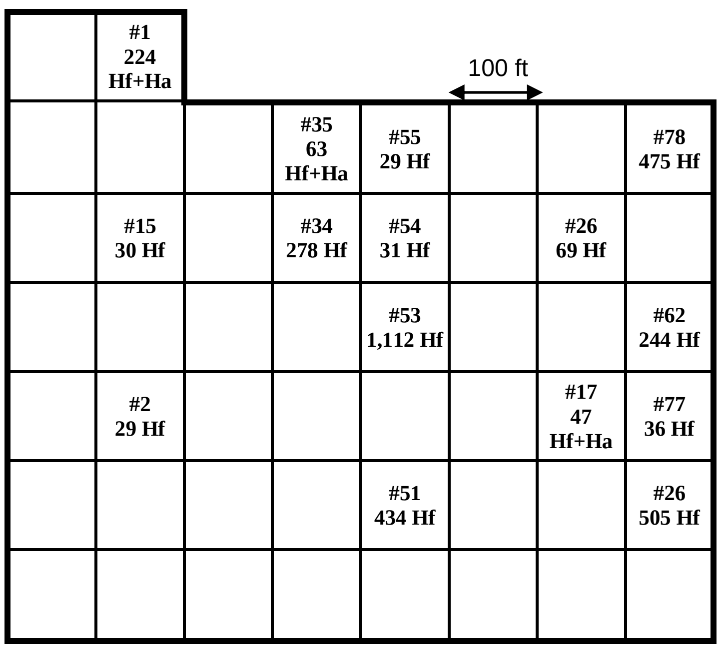

Figure 1. Cyst nematodes at 50 sampling sites within a field near Imbler, Oregon. Sampling was performed at 100- by 100-ft grid intervals. Information shown for each sampling site includes the grid number (#) and the number and species of cereal cyst nematode juveniles in 1 lb of soil. Nematodes were extracted from soil using the Whitehead tray method and species (Ha = *Heterodera avenae* and Hf = *H. filipjevi*) were identified by a molecular diagnostic procedure (PCR-RFLP). Sampling grids that are blank in this diagram did not contain a detectable level of either species. The previous crop in this field was winter wheat cv. 'Chukar', and the sampling date was April 17, 2008.

Nematode DNA from all of the 15 CCN-infested grid sites produced a single, robust band of approximately 1,200 bp when amplified with the *Heterodera*-specific primer pair and PCR using the procedure as reported by Bekal et al. (1997) and Rivoal et al. (2003), indicating these cyst nematodes were from the genus *Heterodera*.

RFLP analyses of the PCR products with four digestion enzymes (*Taq*I, *Hinf*I, *Pst*I, and *Hae*III) revealed that the banding patterns from 12 grid sites (numbers 2, 15, 26, 29, 34, 51, 53, 54, 55, 62, 77, and 78) were the same as that of the previously verified *H. filipjevi* control sample from France but were different from the control sample of *H. avenae*. The banding patterns were also different than those of the control samples of *H. latipons* and *H. schachtii* when digested with *Taq1* and *HaeIII*, ruling out the possibility that the nematodes in these sites could be *H. latipons* or *H. schachtii*. The cyst nematodes from these 12 sites were therefore identified as *H. filipjevi*, which further supports the first report of the presence of this species in Oregon (Smiley et al. 2008). The RFLP banding patterns for three of these sites with *Taq*I are shown in Figure 2.

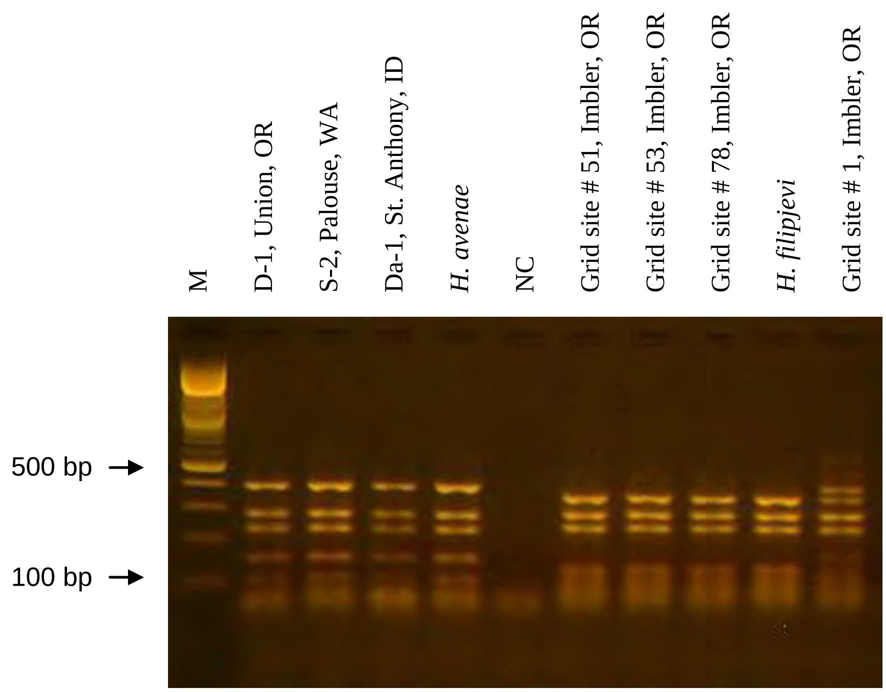

Figure 2. PCR-RFLP profiles of cyst nematodes from fields D-1 (Union, OR), S-2 (Palouse, WA), Da-1 (St. Anthony, ID), and grid sampling sites number 1, 51, 53, and 78 (Imbler, OR) using *Taq*I enzyme. *H. avenae* and *H. filipjevi* are the control species obtained from France. M is the 100-bp DNA ladder. NC represents negative control without any nematode DNA template.

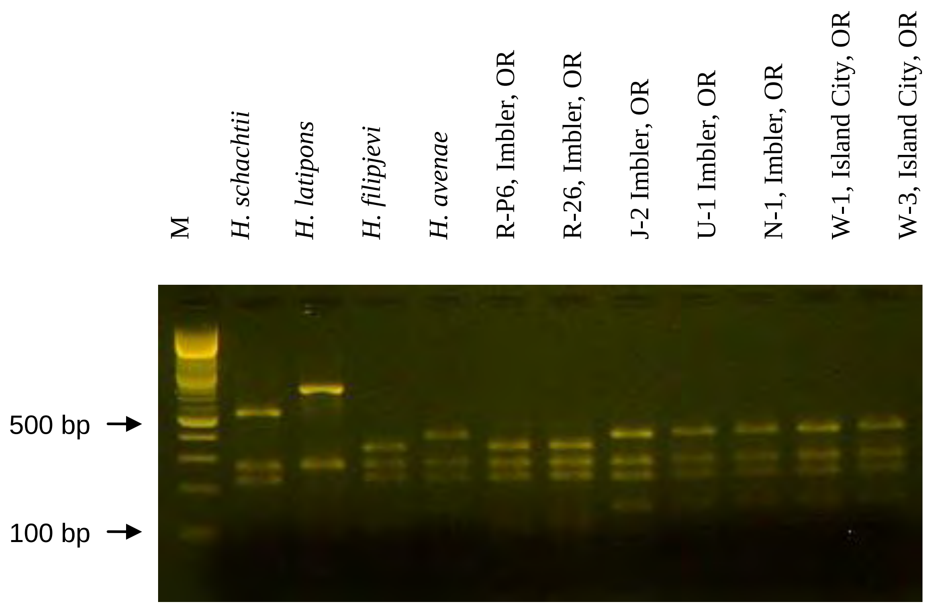

Figure 3. PCR-RFLP profiles of cyst nematodes from fields R-P6, R-26, J-2, U-1, N-1, W-1, and W-3 in Union County, Oregon with *Taq*I digestion. *H. schachtii*, *H. latipons*, *H. filipjevi*, and *H. avenae* are the control species acquired from France. M is the 100-bp DNA ladder.

However, the other three grid sites (1, 17, and 35) showed a different type of banding pattern than that of the control samples of *H. filipjevi*. They not only had all the fragments produced by *H. filipjevi* but also possessed all the specific fragments produced by *H. avenae*, indicating that these sites contained a mixture of *H. filipjevi* and *H. avenae*. The RFLP banding pattern for site number 1 with *Taq*I is shown in Figure 2 (last lane). Another field (R-P6) in the same farm was sampled and the cyst nematode species at this site was also identified as *H. filipjevi* by the PCR-RFLP analysis as shown in Figure 3.

To disclose the diversity and distribution pattern of cyst nematode species in the surrounding area in Union County, seven soil samples were collected from four other farms near Imbler and Island City, Oregon (Table 1). Nematode extraction showed that all the soils were infested with cyst nematodes. Five samples had population densities of less than 400 eggs and juveniles/lb of soil. One sample (W-3) contained a population density that exceeded 1,000 eggs and juveniles/lb of soil. Four restriction enzymes (*Taq*I, *Hinf*I, *Pst*I, and *Hae*III) applied to the PCR products revealed a banding pattern identical to that of the *H. avenae* DNA standard and distinct from the pattern of *H. filipjevi*. The banding patterns were also different from those of the controls for *H. latipons* and *H. schachtii* when digested with *Taq*1 and *Hae*III. Therefore, the cyst nematodes from these sites were determined to be *H. avenae*. The PCR-RFLP profiles for five of these soil samples with *Taq*I are shown in Figure 3. The PCR-RFLP analysis using *Taq*I also confirmed that the cysts from the farm near Union, Oregon was *H. avenae*, as shown in Figure 2 (lane 2), which supports the previous morphological identifications. All the soil samples collected in Union County from fields sampled specifically because they contained irregularly shaped patches of stunted plants were found to be infested with *H. avenae*, proving that this parasite is widely distributed in Union County fields.

Table 1. Soil samples from different locations in the PNW and population densities of cyst nematodes (CN) and species identity determined by PCR-RFLP; fields sampled after a broadleaf (non-host) crop was planted to wheat before the crop that is shown in the table.

Soil name	Location (nearest town)	Sampling date	Previous crop	CN density	*Heterodera* species
D-1	Union, OR	May, 2005	wheat	unknown	*H. avenae*
St-1	Paul, ID	May, 2007	barley	932[a]	*H. schachtii*
St-2	Paul, ID	May, 2007	barley	668[a]	*H. schachtii*
R-P6	Imbler, OR	Apr, 2008	wheat	132[b]	*H. filipjevi*
R-26	Imbler, OR	May, 2008	wheat	55[c]	*H. filipjevi*
J-1	Imbler, OR	May, 2008	wheat	182[c]	*H. avenae*
J-2	Imbler, OR	May, 2008	wheat	191[c]	*H. avenae*
U-1	Imbler, OR	May, 2008	wheat	145[c]	*H. avenae*
N-1	Imbler, OR	May, 2008	wheat	18[c]	*H. avenae*
W-1	Island City, OR	Oct, 2008	wheat	982[c]	*H. avenae*
W-2	Island City, OR	Oct, 2008	wheat	327[c]	*H. avenae*
W-3	Island City, OR	Oct, 2008	wheat	1,364[c]	*H. avenae*
S-1	Palouse, WA	Oct, 2008	chickpea	1,636[c]	*H. avenae*
S-2	Palouse, WA	Oct, 2008	chickpea	4,436[c]	*H. avenae*
S-3	Palouse, WA	Oct, 2008	chickpea	1,209[c]	*H. avenae*
Da-1	St Anthony, ID	Oct, 2008	potato	24,000[c]	*H. avenae*
Da-2	St Anthony, ID	Oct, 2008	potato	19,500[c]	*H. avenae*
Da-3	St Anthony, ID	Oct, 2008	potato	21,491[c]	*H. avenae*

[a] The density represents the number of eggs and juveniles from cysts in 1 lb of soil.
[b] The density represents only the number of juveniles extracted from 1 lb of soil using the Whitehead tray method.
[c] The density represents the total number of eggs and juveniles in 1 lb of soil, as reported by Western Laboratories (Parma, ID).

Six soil samples collected during October 2008 from infested fields near Palouse, Washington and St. Anthony, Idaho (Table 1) also revealed very high populations of cyst nematodes. The three samples from Washington had population densities from 1,200 to 4,400 eggs and juveniles/lb of soil. The three samples from Idaho had populations of about 20,000 eggs and juveniles/lb of soil, representing densities at least 20 times higher than that required to cause significant yield loss in wheat. The amplified DNA from all of the samples produced the same banding pattern as that of *H. avenae* and different from that of *H. filipjevi* when digested with the four previously mentioned restriction enzymes, and produced banding patterns different than those of *H. latipons* and *H. schachtii* when digested with *Taq*1 and *Hae*III, suggesting that the species of cyst nematode in the Washington and Idaho fields was *H. avenae*. The PCR-RFLP profiles for two of these samples with *Taq*I are shown in Figure 2 (lanes 3 and 4).

The growers who allowed soils to be collected from their fields for use in our research were unaware that a high population of cyst nematodes was a possible reason for the patchiness and reduced wheat yields they were experiencing. Rotation of wheat with any broadleaf crop species was recommended to these growers. However, crop rotation does not allow sufficiently intensive wheat production and thereby grain growers may not find it profitable. The use of resistant varieties offers the most effective and economic option to control damage from these nematodes. If sources of genetic resistance to *H. avenae* and *H. filipjevi* can be successfully identified and incorporated into popular varieties, the grain growers in Oregon, Idaho, and Washington will be able to achieve higher grain yields on infested fields.

The restriction enzymes *Rsa*I and *Alu*I were used to investigate intraspecific variation within *H. filipjevi* populations or *H. avenae* populations on a conserved domain (ITS region) of the DNA sequences. Intraspecific polymorphism was not observed within *H. filipjevi* populations from Oregon and France, as shown in Figure 4 with *Rsa*I digestion and Figure 5 with *Alu*I digestion. These results indicate that the two *H. filipjevi* populations are genetically similar based on the ITS region. There was also no intraspecific polymorphism within *H. avenae* populations from Oregon, Washington, and Idaho. The PNW populations we examined therefore appeared to be genetically similar based on the ITS region. However, intraspecific polymorphism was observed between the PNW *H. avenae* populations and the French population. *Rsa*I did not digest the PCR products of the PNW populations, showing only a single band, but did digest the PCR product of the French population (IB), resulting in two additional bands (Fig. 4). *Alu*I slightly digested the PCR fragments of the PNW populations, producing one weak band (180 bp), but digested the PCR fragment of the French population, producing two bands (180 bp and 700 bp) (Fig. 5).

*Rsa*I and *Alu*I digestions permitted differentiation of these PNW *H. avenae* populations from the French population. Subbotin et al. (1999) reported that three genetic types of ITS regions were identified for *H. avenae* populations using *Rsa*I and *Alu*I. Type A showed only one unrestricted band; type B showed only two additional bands; and type A+B had their combination (one unrestricted band with two additional bands). Type A was therefore identified for the PNW populations and type A+B was identified for the French population (IB). These different genetic types generally corresponded to the populations with similar morphological types.

Although the intraspecific variation was not found for the *H. avenae* populations from Oregon, Washington, and Idaho based on the conservative domain (ITS region) of DNA sequences, these populations may have different abilities in attacking wheat cultivars if other functional genes responsible for pathogenicity are different. Pathotype tests with a specialized international test assortment including a set of wheat, barley, and oat cultivars are necessary to determine the virulence of *H. avenae* populations. The high populations of *H. avenae* found in the soil samples collected from Oregon, Washington, and Idaho make these tests possible. Pathotype testing experiments using 27 wheat, barley, and oat differential cultivars are currently underway.

Soil samples St1 and St2 from an irrigated barley field near Paul, Idaho were tested because the cysts in that soil had been identified as *H. avenae* by a commercial nematode testing laboratory in Oregon. The soil samples from that field were found in our tests to be infested by *H. schachtii*. *Taq*I digestion showed that the samples produced the same banding pattern as that of the control specimen of *H. schachtii* and were different from patterns of *H. filipjevi*, *H. avenae,* and *H. latipons* (Fig. 6A). The cysts also produced the same banding pattern as that of *H. schachtii*, distinct from those of *H. avenae* and *H. filipjevi,* when digested with *Hinf*I (Fig. 6B). The beet cyst nematode (*H. schachtii*) found in soil under the barley crop likely originated from the nematode's reproduction on a host plant such as sugar beet in a previous rotation on that field, or through contamination of the field with soil from a beet field. The geographic origin of the sample (Minidoka County, Idaho) was in a beet-growing county.

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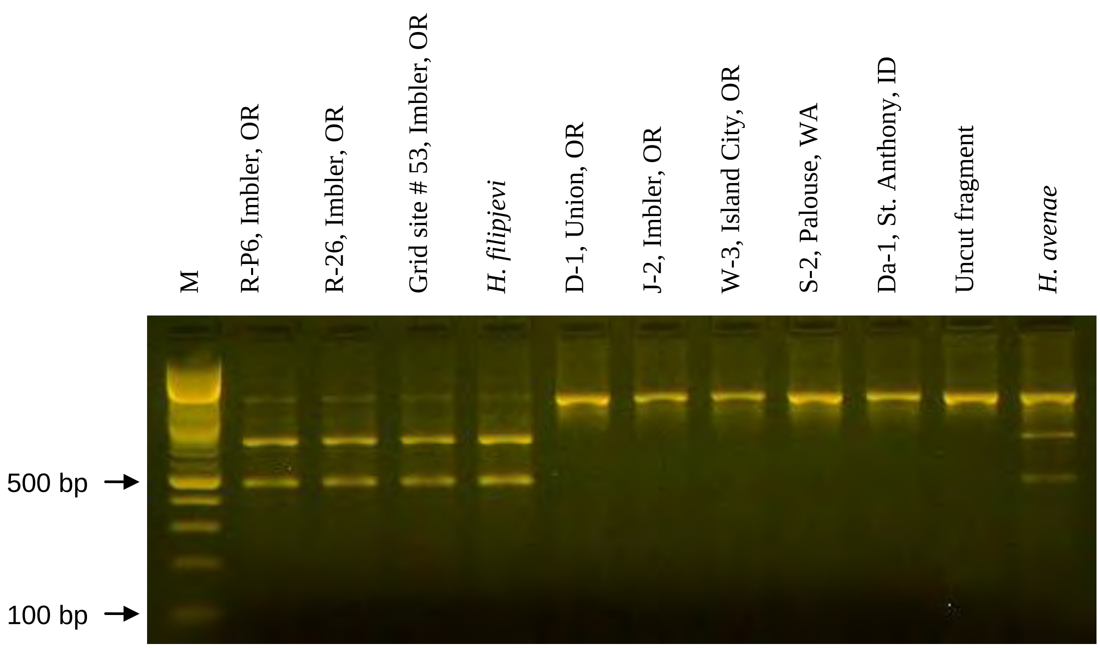

Figure 4. PCR-RFLP profiles of cyst nematodes with *Rsa*I digestion. Amplified DNA were from fields R-P6, R-26, grid site number 53, D-1 , J-2 , and W-3 in Union County, Oregon; S-2 near Palouse, Washington; and Da-1 near St. Anthony, Idaho. "Uncut fragment" represents the original PCR product that was not digested with any restriction enzyme. *H. filipjevi* and *H. avenae* are the control species acquired from France. M is the 100-bp DNA ladder.

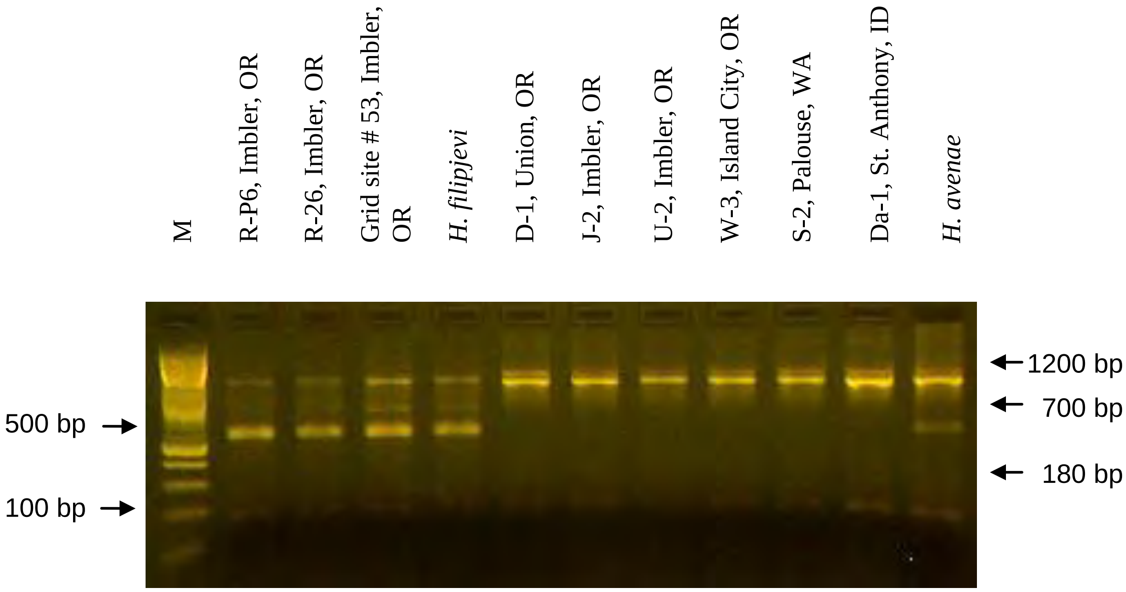

Figure 5**.** PCR-RFLP profiles of cyst nematodes with *Alu*I digestion. Amplified DNA were from fields R-P6, R-26, grid site number 53, D-1, J-2, U-1, and W-3 in Union County, Oregon; S-2 near Palouse, Washington; and Da-1 near St. Anthony, Idaho. *H. filipjevi* and *H. avenae* are the control species from France. M is the 100-bp DNA ladder.

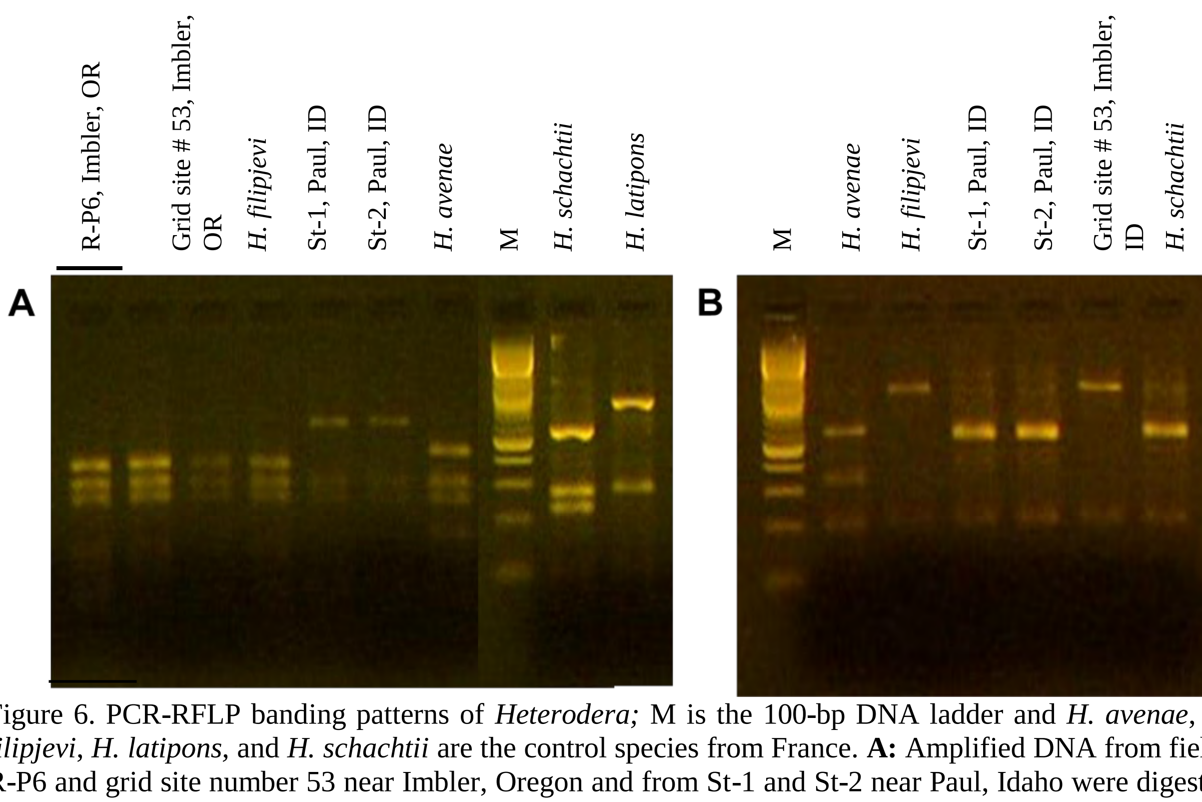

Figure 6. PCR-RFLP banding patterns of *Heterodera;* M is the 100-bp DNA ladder and *H. avenae*, *H. filipjevi*, *H. latipons,* and *H. schachtii* are the control species from France. **A:** Amplified DNA from fields R-P6 and grid site number 53 near Imbler, Oregon and from St-1 and St-2 near Paul, Idaho were digested with *Taq*I. **B:** Amplified DNA from fields St-1 and St-2 and grid site number 53 were digested with *Hin*fI.

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Hard Red Winter Wheat Production in Eastern Oregon: Varieties and Nitrogen Management

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Abstract

Proper nitrogen (N) management and variety selection are important for profitable hard red winter (HRW) wheat production in eastern Oregon. However, N management for grain yield and protein is challenging due to climatic and year-to-year variations in low to intermediate rainfall (12-18 inches) production environments. Experiments at three locations in eastern Oregon were initiated in 2006 to study the effects of variety, N fertilizer, and location on grain yield and protein of HRW wheat. The new HRW varieties 'Norwest 553' and 'AgriPro Paladin' produced similar or higher grain yields and higher grain protein than the standard variety 'Boundary'. In addition, grain yields of HRW varieties were competitive with the soft white winter (SWW) variety 'Stephens'. Minimal grain yield response to N fertilizer was observed. However, grain protein response to N fertilizer was significant, and varied by year and location. Some site-years proved favorable for efficient production of high protein HRW, whereas acceptable protein concentrations were very difficult to achieve in others. Nitrogen requirements for grain yield and protein appear to be more stable in the intermediate rainfall zone, suggesting this environment may be more suitable for HRW production.

Keywords: grain protein, grain yield, hard red winter, nitrogen fertilizer, wheat

Introduction

Soft white winter (SWW) wheat is the main market class of wheat produced in Oregon and the Pacific Northwest. However, the production of nontraditional market classes such as hard red winter (HRW) wheat has the potential to increase grower profitability. At Portland, the HRW premium over soft white has averaged $0.50/bu and ranged from less than SWW to greater than $1.50/bu over the last 10 years (Fig.1). However, grain protein levels of 11.5–12.5 percent are required to obtain these premiums. Thus despite the potential for increased profits, acreage of HRW in eastern Oregon remains relatively low due to the difficulties of consistently meeting market expectations for grain protein and quality, for which nitrogen (N) management and variety selection are critical.

Proper N management is essential to successfully produce HRW wheat that meets both grain yield and protein expectations. Achieving target protein levels of 12 percent or greater requires more N fertilization than is necessary for maximum yield. On average, current N fertilizer recommendations call for an increase of 0.8 lb N/bu for HRW wheat compared to SWW wheat (Lutcher et al. 2007). However, actual values may be higher or lower depending on growing conditions in each year and among locations.

Increasing the complexity of N management for yield and protein are environmental factors such as climate, rainfall amount and timing, and temperature during grain fill (Rao, 1993).

Variation among these factors in the dryland growing regions of eastern Oregon requires unique N management considerations for each location and crop year. Generally, it is believed that HRW is most suited to the high stress and lower yielding regions of eastern Oregon because of the often observed negative relationship between yield and protein. However, research on both irrigated HRW and hard red spring wheat has shown that with proper N management both yield and protein targets can be obtained in low stress, high yielding environments (Brown, 2006)(Brown, 2005)

In addition, genetics greatly influence agronomic performance and grain quality. Thus, variety selection is critical to the successful production of HRW. Anecdotal evidence from the Oregon State University statewide variety trials suggests that some new HRW varieties express improved N use efficiency through increased grain protein contents (Flowers et al. 2008), but further research is required to confirm these observations.

Therefore, a study was initiated in fall 2006 to evaluate several HRW wheat varieties across a range of environments in eastern Oregon. Our study objectives were:

1) To compare new HRW varieties to commonly grown HRW and SWW wheat varieties.
2) To measure the yield and protein response to increasing levels of N fertilization across several environments in eastern Oregon.

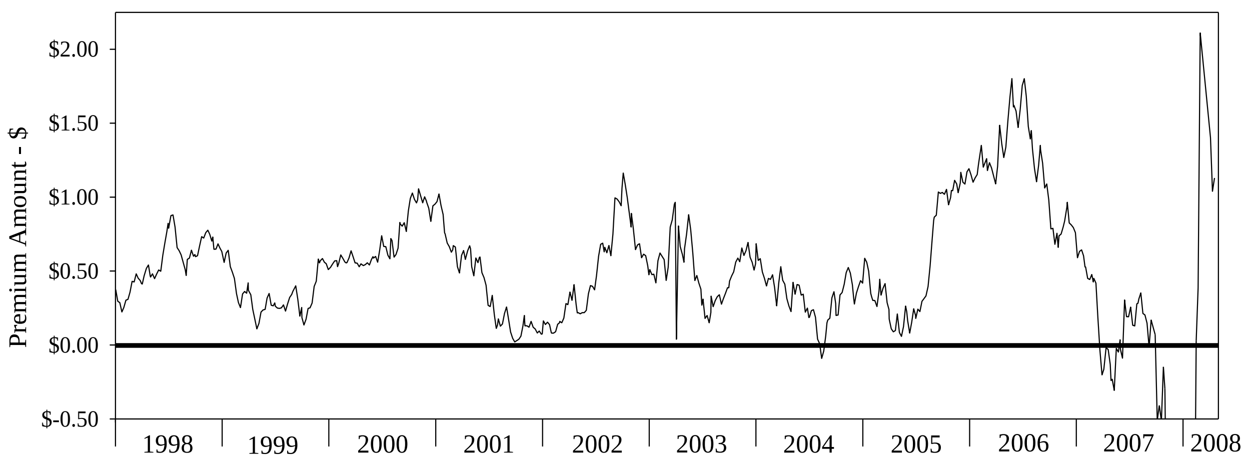

Figure 1. The price premium ($) of 12 percent protein hard red winter wheat over soft white wheat at Portland from 1998 to August 2008. Source: USDA Agricultural Marketing Service, Portland, Oregon.

Methods

Field trials were established at three locations across a range of environments in the 2006-2007 and 2007-2008 growing seasons. An intermediate rainfall site (16 inches annual precipitation) was located at the Pendleton station of the Columbia Basin Agricultural Research Center. Additionally, two low rainfall sites (10-12 inches annual precipitation) were located near Lexington and Helix, Oregon. All locations were fallow the previous crop year. The Pendleton and Helix sites were conventionally tilled, while the Lexington site was no-till. The Pendleton site was planted October 6 in 2006 and October 15 in 2007. Helix was planted on October 17 in 2006 and October 26 in 2007, and Lexington on September 27 in 2006 and September 26 in 2007. A randomized complete block design was used at all locations. Treatments included four wheat varieties, and seven fall N fertilizer rates. Varieties evaluated included three HRW wheats ('Norwest 553', Agripro 'Paladin', and 'Boundary') along with a SWW wheat control ('Stephens').

Nitrogen treatment rates were varied by rainfall zone and yield potential. Nitrogen rates at Pendleton ranged from 0 lb N/acre to 300 lb N/acre in 50-lb increments. Fall N applications at Lexington and Helix ranged from 0 lb N/acre to 150 lb N/acre in 25-lb increments. Nitrogen fertilizer was applied prior to seeding using a small-plot drill to band N approximately 2 inches to the side of the seed row. Granular urea (46-0-0) was the N source at all sites. Additionally, 12 lb sulfur/acre as potassium magnesium sulfate (K mag; 0-0-22-22) was applied to all the plots at the same time as the N.

Soil residual N (nitrate and ammonium) was measured following planting. Soil cores were taken in 1-ft increments to a depth of 3 ft from two plots receiving no fall N in each experimental block. Cores from each depth increment were pooled, homogenized, and a subsample taken for laboratory analysis. Samples were held in a cooler with ice to prevent mineralization and volatile N losses until laboratory analysis.

Plots were harvested at physiological maturity using a Hege small plot combine. Grain weight, moisture, and test weight were recorded, and yield reported as adjusted to 12 percent moisture. Grain protein concentration was determined by NIR with a Foss Grain Analyzer. Data were analyzed with SAS statistical software, and means determined and separated using the LSMEANS option in PROC GLM (SAS 2003). Analyses were performed separately for each year and location.

Results and Discussion

Analysis of variance indicated that significant interactions among variety, N rate, year, and location exist (data not shown). This is not surprising given the large environmental differences between locations and years. Thus, to improve our understanding of the main effects of variety and N rate, data were analyzed separately by location and year.

Variety evaluation

Significant differences among varieties were observed in most site years (Table 1). The HRW wheat varieties 'Norwest 553' and 'Boundary' consistently had the highest grain yields, often showing significantly greater yield than 'Stephens' (Table 1). 'AgriPro Paladin' produced yields that were at least as good as 'Stephens', and competitive with 'Norwest 553' in the drier environments of Lexington and Helix. If yield was the only consideration, both 'Norwest 553' and 'Boundary' would be good choices for the range of production regions in eastern Oregon, while 'AgriPro Paladin' may fit well in the driest areas.

However, a good HRW variety must yield well while achieving an acceptable level of grain protein. Table 1 shows that the newer varieties 'Norwest 553' and 'AgriPro Paladin' produced significantly higher grain protein content than 'Boundary'. The grain protein content of 'Norwest 553' ranged from 0 to 1.3 percent greater than 'Boundary' across the 6 site-years. Similarly, the grain protein content of 'AgriPro Paladin' ranged from 0 to 1.1 percent greater than ‘Boundary’ across the 6 site-years. Compared to each other, neither ‘Norwest 553’ nor ‘AgriPro Paladin’ consistently achieved higher grain protein than the other. However, lower yields of ‘AgriPro Paladin’ at similar protein levels suggest that ‘Norwest 553’ may achieve grain protein more efficiently. Additional research is needed to confirm this observation.

Table 1. Mean yield and protein values averaged across all nitrogen treatments for one soft white and three hard red winter wheat varieties at three locations in 2007 and 2008.

2007	Lexington		Pendleton		Helix	
Variety	Yield	Protein	Yield	Protein	Yield	Protein
Stephens	40.3 B*		92.0 A		42.4 B	
Norwest 553	43.1 AB	14.1 a**	72.8 C	12.1 a	46.8 A	14.3 a
Agripro Paladin	42.1 B	13.4 b	89.9 A	12.3 a	47.1 A	13.4 b
Boundary	46.6 A	12.8 c	82.7 B	12.3 a	44.6 A	13.6 ab
2008						
Variety						
Stephens	30.7 B		91.8 A		59.4 C	
Norwest 553	36.7 A	10.9 b	90.9 AB	12.2 a	64.8 BA	12.8 b
Agripro Paladin	31.8 B	11.8 a	86.2 B	12.3 a	62.9 BC	13.3 a
Boundary	35.2 A	10.7 b	94.4 A	11.5 b	69.3 A	12.3 c

*Mean yield within a site-year followed by the same capital letter not significantly different at the 0.05 significance level.
**Mean proteins within a site-year followed by the same lowercase letter not significantly different at the 0.05 significance level.

Thus, our data show that the HRW wheat varieties have similar yields to the commonly grown SWW wheats in the low and intermediate rainfall regions of eastern Oregon. Among HRW wheat varieties, ‘Norwest 553’ would be the best choice because it had both high grain yields and higher grain protein content compared to other varieties. ‘AgriPro Paladin’ would also be a good choice for many production regions as it had competitive yields and higher grain protein content compared to ‘Boundary’.

Response to nitrogen at Pendleton

Response to N fertilizer was significant in both years, and was significantly influenced by differences in annual precipitation, temperature, and residual soil N. Crop year precipitation at Pendleton totaled 15.0 and 13.9 inches in 2007 and 2008, respectively (Table 2). Rainfall in both 2007 and 2008 was lower than the long-term average of 16 inches per year. Despite the lower rainfall in 2008, grain yield averaged 8.4 bu/acre more than in 2007.

Table 2. Yield, protein, and corresponding coefficients of variation (CV) with soil residual nitrogen (N) and crop-year precipitation (inches) values for all study sites.

	2007			2008		
	Lexington	Helix	Pendleton	Lexington	Helix	Pendleton
Mean yield	44.0	44.5	82.1	34.7	65.7	90.5
Protein mean	13.5	13.5	12.3	11.1	12.7	12.0
Yield CV	16.1	12.8	10.8	12.0	11.5	8.8
Protein CV	6.7	9.4	7.0	5.1	3.6	5.5
Soil N (lb/a)	102.9	182.1	87.2	42.3	108.0	105.8
Rainfall (inches)	15.0	n/a	13.9	10.7	n/a	8.1

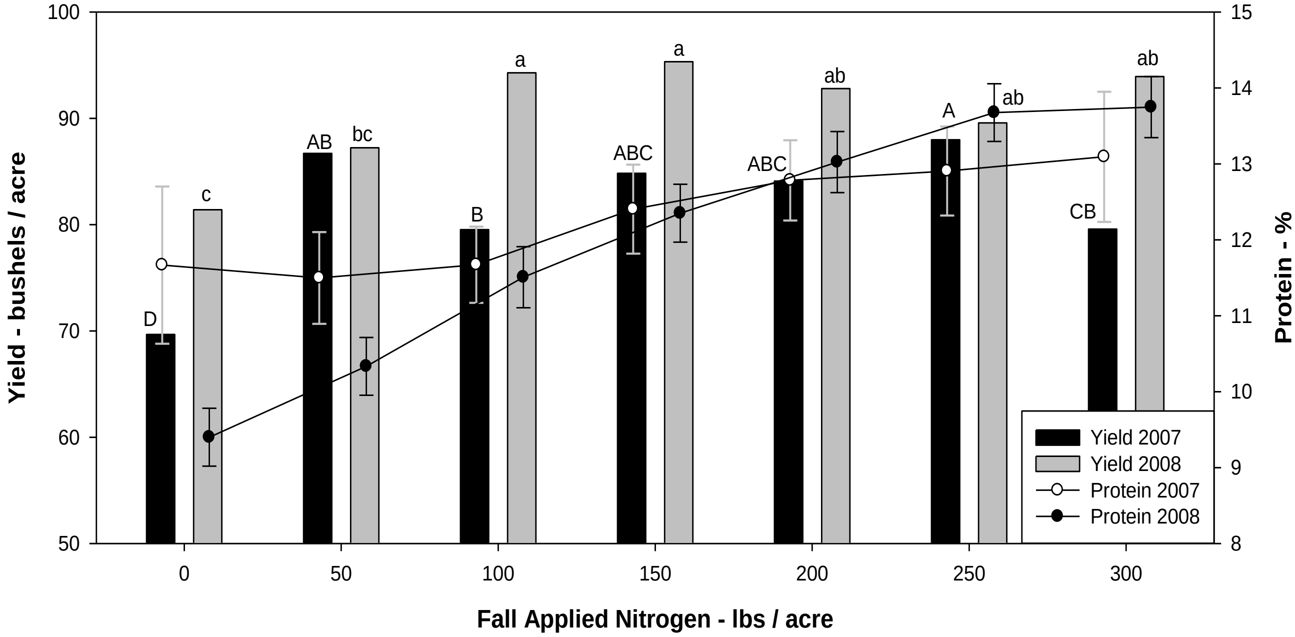

Figure 2. Pendleton mean yield and protein of three hard red winter varieties across a range of nitrogen (N) fertilizer levels in 2007 and 2008. Bars with same letter are not significantly different at the 0.05 significance level. Capital letters denote mean yield differences between N fertilizer rates in 2007, while lowercase letters denote differences in 2008. Confidence limit bars (95 percent) are given for all protein means.

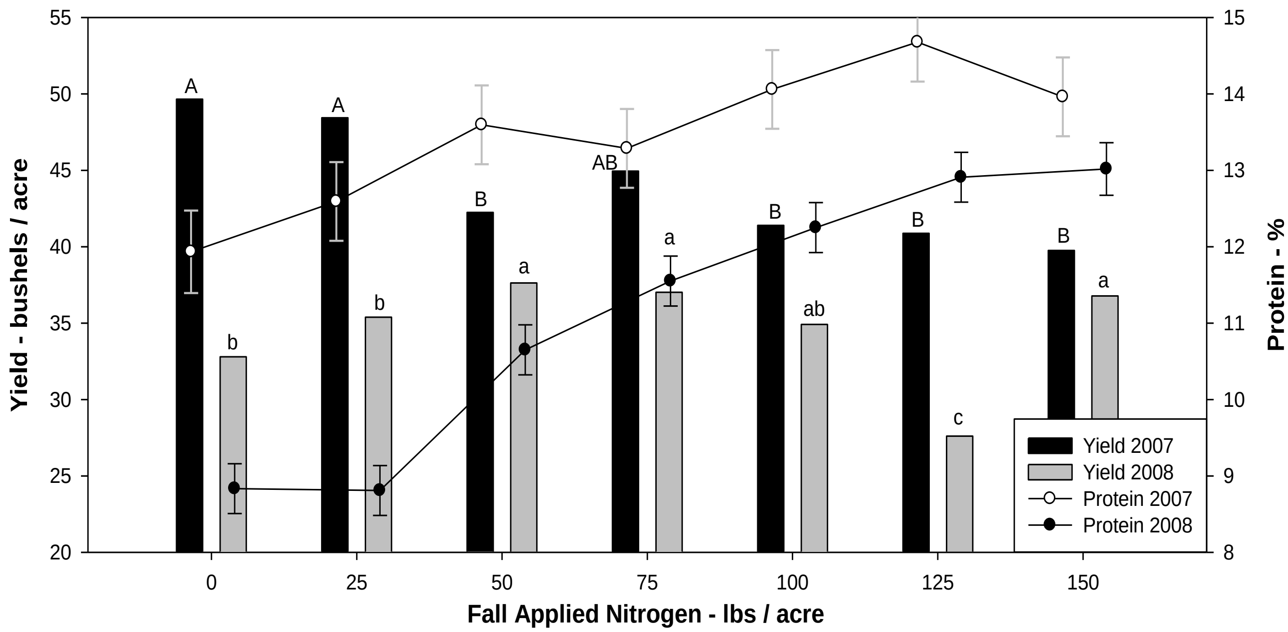

Figure 3. Lexington mean yield and protein of three hard red winter varieties across a range of nitrogen (N) fertilizer levels in 2007 and 2008. Bars with same letter are not significantly different at the 0.05 significance level. Capital letters denote mean yield differences between N fertilizer rates in 2007, while lowercase letters denote differences in 2008. Confidence limit bars (95 percent) are given for all protein means.

In 2007, grain yield was increased by the addition of 50 lb of N fertilizer (Fig. 2). No further yield increases were observed with additional N fertilizer. In 2008, grain yield significantly increased with the addition of both 50 and 100 lb of N fertilizer.
After 100 lb of N, we observed no further significant yield increases. These results are not surprising, considering the relatively high soil residual N present in both years (Table 2).

In both 2007 and 2008, grain protein significantly increased with the addition of fertilizer N (Fig. 2). In 2007, more than 50 lb/acre of additional N above that needed for grain yield were required to raise grain protein to 12 percent. Similar results were found in 2008. Interestingly, in 2008 grain yield and protein increased together with additional N, demonstrating that conditions can be conducive to both high grain yield and protein.

Although variances and response to N among years are difficult to evaluate due to spotty stands and high variance in 2007, it is notable that the same average protein was achieved in both years. Neither required an excessive amount of N to meet target protein after considering yields. This suggests that quality HRW production in the intermediate rainfall regions of eastern Oregon can be both efficient and stable.

Response to nitrogen at Lexington

Significant responses to N were also observed at Lexington. Similar to Pendleton, environment contributed to differences between years. Crop year precipitation totaled 10.7 and 8.1 inches at Lexington in 2007 and 2008, respectively. In 2008 an unusual dry period occurred from February through early May, which resulted in 2008 mean yields of 9 bu/acre less than in 2007 (Table 2).

In 2007, the addition of N fertilizer did not significantly increase grain yield (Fig. 3). This was likely due to the high soil residual N (Table 2). Low soil residual N with the addition of 50 lb N/acre in 2008 resulted in a significant yield increase. No further significant yield increases were found with additional N fertilizer beyond 50 lb N/acre. In both years, N in excess of requirements for yield reduced grain yield.

Grain protein response to N fertilizer was significant in both years (Fig. 3). The response to N fertilizer was quadratic, with grain protein leveling off at the highest N levels. Average grain protein values were much higher in 2007 due to high residual soil N. In fact, no additional N fertilizer was required to reach a target protein of 12 percent. Results for 2008 were quite different. More than an additional 25 lb N/acre beyond that required for yield was needed to raise grain protein to 12 percent. Even after accounting for a reduced amount of residual soil N, achieving 12 percent grain protein in 2008 required a large quantity of N relative to 2007. This may have been caused by the unseasonably dry spring in 2008.

Our results indicate that HRW production at Lexington (and in the low rainfall region of eastern Oregon) may in fact be a more risky practice compared to HRW production in the intermediate rainfall regions of eastern Oregon. These results are contrary to current opinion, which assumes that low rainfall regions more consistently achieve acceptable grain protein levels than higher rainfall locations.

Response to nitrogen at Helix

Response to N at Helix is not included in this report. Excessively high residual soil N at this low yield potential site masked meaningful differences between N treatments (Table 2).

Conclusions

Results from the first 2 years of this 3-year study show clear grain yield and protein differences among varieties and N treatments. Environmental conditions including residual soil N, rainfall, and temperature also influenced grain yield and protein. Among HRW varieties, 'Norwest 553' was found to be the most consistent for both high yields and high grain protein across 6 site-years. Large differences between N requirements for target protein between years and locations underscore the inherent risk involved with growing HRW. However, in contrast to traditional views, lower and more consistent N requirements at Pendleton suggest that higher yielding environments may be more suitable for HRW production. High stress environments such as Lexington may if fact be riskier due to the greater variability in protein contents found in this study.

Acknowledgments

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USDA-ARS Club Wheat Breeding in Oregon

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Abstract

Club wheat is commonly grown in Washington and northeastern Oregon and usually marketed as a mixture with soft white wheat called 'Western White'. The goal of the USDA-Agriculture Research Service Club Wheat Breeding Program is to improve club wheat cultivars, especially to increase yields and disease resistance, and to maintain the excellent end-use quality that characterizes the class. The objective of this research was to evaluate preliminary and advanced winter club wheat breeding lines in northeastern Oregon to develop competitive winter club cultivars suited for these growing conditions. Four locations were used to evaluate 15 breeding and 4 Western Regional Cooperative nurseries for early spring growth, winter damage, heading date, height, disease, grain yield, test weight, and quality. Coleoptile length measurements were taken on advanced breeding lines to identify genotypes with long coleoptiles to improve deep planting emergence.

Key words: club wheat, coleoptile length, Western White, wheat breeding

Introduction

In the 2008 harvest year, club wheat was grown on 10,000 acres in Oregon and more than 125,000 acres in Washington, which accounts for 1 percent and 5 percent of the total wheat crop in each respective state. In the United States, club wheat is grown only in the Pacific Northwest. Club wheat is a type of soft white wheat with a compact head morphology. Club wheat produces a characteristic weak-gluten, low-protein flour with high break flour extraction that is desired by the milling and baking industry for cakes and pastries. Most of the club wheat crop produced is exported in a mixture with soft white wheat known as 'Western White'. The club wheat breeding program has been an important and productive part of the research at the Columbia Basin Agricultural Research Center (CBARC) since the 1950's. The program is now coordinated from the USDA-Agricultural Research Service (ARS) Wheat Genetics, Quality, Physiology, and Disease Research Unit at Pullman, Washington under the direction of Dr. Kim Garland Campbell with technical assistance provided by Jeron Chatelain at CBARC and Adrienne Burke, Chris Hoagland, and Lesley Murphy at Pullman. Administrative oversight in Oregon is provided by Steve Petrie. Dr. K. Garland Campbell is also coordinator of the Western Regional Cooperative Nurseries. The goal of the program is to improve emergence, cold tolerance, disease resistance, and yield potential of club wheat cultivars to reduce grower risk, as well as improve end-use quality. The objective of this research was to evaluate preliminary and advanced winter club wheat breeding lines at several locations in northeastern Oregon with the goal of developing competitive winter club cultivars suited for these growing conditions, with high genetic resistance to major disease and excellent end-use quality.

Materials and Methods

Four northeastern Oregon locations (Pendleton, Moro, Lexington, and Hermiston) were used for 15 breeding and 4 Western Regional nurseries. All sites were dryland except Hermiston, which was pivot irrigated. The Pendleton nurseries were located at CBARC and the Moro nurseries were at the Sherman Experiment Station. The other two locations were Madison Farms near Hermiston with cooperator Kent Madison, and Starvation Farms north of Lexington with cooperator Chris Rauch. Average annual precipitation at Pendleton is 17 inches, Moro receives 11 inches, and Lexington and Hermiston receive about 10 inches.

Pendleton

Replicated winter wheat nurseries were planted October 5, 2007 at CBARC into conventional fallow. The yield trial nurseries evaluated were the USDA-ARS Oregon Elite and USDA-ARS Washington Elite, consisting of 24 entries replicated 4 times, and the USDA-ARS Preliminary 1, Preliminary 2, Preliminary 3, and Preliminary 4 nurseries, consisting of 36 entries each and replicated 3 times. Two cooperative regional nurseries were evaluated, the Western Regional Soft Winter Wheat Nursery and the Western Regional Hard Winter Wheat Nursery, comprised of 36 and 22 entries, respectively, with 3 replications. All replicated trials were arranged in a partially balanced lattice design. The ARS unreplicated yield trial (08 F7 Yield) was planted October 15, 2007 and included breeding lines from early generation material. Included in the unreplicated nursery were the check cultivars ‘Brundage96’, ‘Chukar’, and ‘Tubbs’ alternately spaced about every 12 entries. All seed, excluding the ARS unreplicated 08 F7 Yield trial, was treated prior to planting with Dividend® at recommended label rates. The seeding rate was approximately 20 seeds/ft^2. Plots were seeded at a depth of 1-1.5 inches using a five-row Hege drill with double-disc openers on 12-inch spacing. Plot size was approximately 77.5 ft^2 and seed was planted into moisture, resulting in good emergence. Eighty pounds of nitrogen (N) per acre as anhydrous ammonia and 10 lb of sulfur per acre as Nitrosol® were applied prior to planting. The replicated trials were controlled for broadleaf weeds in the spring with 20 oz/acre of Bronate Advanced™. A spring fertilizer application was applied in early April to the Western Regional Hard Winter Wheat Nursery as Solution 32 at a rate of 20 lb of N/acre. For the ARS unreplicated F7 Yield trial, Hoelon® EC was applied at 2.66 pt/acre and incorporated into the soil prior to planting, and 8 oz/acre Axiom® DF and 2 oz/acre Sencor® DF were applied pre-emergence after planting. Spring weed control on this trial consisted of 13 oz/acre Bronate Advanced and 6 oz/acre Sencor® DF.

All plots were evaluated for early spring growth, winter damage, disease, heading date, height, and lodging. Heading date was defined as days from January 1 until 50 percent of the plot had headed. Due to very low disease pressure or presence, the only disease notes taken were for physiological leaf spot. The unreplicated ARS trial was also evaluated for common bunt. Plots were harvested with a Hege small-plot combine July 28-29, 2008 except for the ARS unreplicated F7 Yield trial, which was harvested August 5-6, 2008. Grain samples were weighed to determine grain yield, cleaned using a small-sample Hege seed cleaner, and test weight was measured. An 800-g sample was saved from one replication for all trials and sent to the Western Wheat Quality Laboratory in Pullman, Washington for quality evaluation.

Moro

Nurseries evaluated at the Sherman Experiment Station included the USDA-ARS Oregon Elite and USDA-ARS Washington Elite yield trials, the USDA-ARS Preliminary 1, Preliminary 2, Preliminary 3, and Preliminary 4 nurseries, and the two cooperative regional nurseries (the Western Regional Soft Winter Wheat Nursery and the Western Regional Hard Winter Wheat Nursery). Trials were planted on October 11, 2007 with a Gaines tip, hoe-opener Hege drill, on 14-inch spacing, about 1-1.5 inches deep into moisture. All seed was treated with Dividend® prior to planting and seeded at approximately 20 seeds/ft^2 in a 77.5 ft^2 plot. There were 126 lb N/acre in the soil and 40 lb N/acre was applied as anhydrous ammonia in the late summer. Hoelon was applied prior to planting at 43 oz/acre and incorporated into the soil twice for downy brome (*Bromus tectorum*) control. On February 18, 2008 Gypsum was applied to the surface at 75 lb/acre. Broadleaf weeds were controlled in the spring by spraying Harmony® Extra at 0.6 oz/acre with 2,4-D amine at 8 oz/acre and 4 oz/acre of Clarity® on April 1. The experimental design and data collected were the same as described for the Pendleton Station. Plots were harvested July 23-24, 2008 using a Hege small-plot combine.

Lexington

The USDA-ARS Oregon Elite yield trial was planted on October 3, 2007 into chemfallow ground using a four-row Hege 1000 drill with double-disc openers on 14-inch spacing, at approximately 20 seeds/ft^2. Seed was treated with Dividend and plot size was approximately 77.5 ft^2. Fertilizer and herbicide applications were managed by the grower. Experimental design and data collected were the same as described for Pendleton, except no quality samples were taken. Plots were harvested July 14, 2008.

Hermiston

On October 4, 2007 the USDA-ARS Oregon Elite yield trial was planted under pivot irrigation using a seven-row Hege 1000 drill with double-disc openers on 8-inch spacing. Fertilizer and herbicide applications were managed by the cooperator and the plots were harvested July 16, 2008. Experimental design and data collected were the same as described for Pendleton, except no quality-evaluation samples were taken.

Coleoptile Length Testing

Coleoptile lengths were measured for advanced USDA-ARS club breeding lines and early generation F6 club material. Multiple check varieties were included for comparison along with long-coleoptile checks ‘Moro’ and ‘Edwin’, and short-coleoptile check ‘Hiller’. These were evaluated as described in Hakizimana et al. (2000) with a few modifications. Fifteen seeds were placed on a wet germination towel 1 cm apart with the germ end down across the middle of the towel. The towel was folded up, rolled loosely, secured with a rubber band, and placed upright in a plastic tray lined with wet germination towels. Samples were placed in a dark growth chamber at 4^{o}C for 4 days, then removed and placed in another dark growth chamber at 15^{o}C for 16 days. Coleoptile lengths were measured to the nearest millimeter and the average length of each cultivar was calculated after removing the highest and lowest value. This technique was used to identify genotypes with long coleoptiles that will readily emerge from deep planting.

Results

Weather throughout the crop year had a significant impact on results. Dry and cool weather in the spring resulted in trials that matured about 1 week later than average. Below normal precipitation and very hot temperatures in mid-May also greatly diminished yield potential, and resulted in yields at Pendleton and at Moro that were approximately 15 and 20 bu/acre lower than their location long-term averages. Test weights also were lower than average, with the Pendleton average being 55 lb/bu and the Moro average 57 lb/bu. The Hermiston trial site had highly variable data and results, possibly due to chemical residue in the water or other unknown causes.

Lines ARS960277L and ARS970075-3C, which have been proposed for breeder seed increase in Washington, yielded the same or higher as soft white check varieties 'Tubbs' and 'Xerpha', and have shown to consistently yield the same or better than the check varieties in numerous trial locations and years. Likewise, line X970184-1C from the Oregon-Elite trial (Table 1) and X970048C from the Washington-Elite trial yielded the same as the top soft white check variety of the nurseries in Pendleton and Moro.

Table 1. Agronomic trait data for 2008 USDA-ARS Oregon-Elite Nursery.

	Grain yield					Heading date[b]	Height	Test weight
	Lexington	Hermiston	Pendleton	Moro	Pullman[a]			
	bu/acre					from 1/1	in	lb/bu
Brundage96	29.2	97.6	85.3	50.2	92	146	30	58.98
Cara	26.6	103.3	83.1	47.3	83	152	28	56.84
Coda	28.7	113.4	75.1	49.6	80	151	31	59.33
Tubbs	30.5	110.3	79.5	52.9	81	147	33	58.68
Xerpha	32.0	128.3	79.9	54.1	93	150	32	59.28
ARS960277L	28.7	94.1	89.4	48.8	88	149	30	58.51
ARS970075-3C	36.5	113.2	80.6	49.6	88	150	30	58.32
ARS970168-2C	27.3	98.6	76.9	47.2	83	149	29	59.84
ARS970042C	29.3	107.0	83.5	49.4	79	150	30	57.46
ARS970108-1C	24.4	102.2	84.9	48.9	84	150	30	56.06
X9602044-2C	24.0	93.1	80.0	47.4	77	148	27	59.70
X960538C	28.7	106.6	80.5	52.5	87	152	28	57.03
X96312t313C	29.9	95.4	83.6	48.5	82	153	32	57.66
X970005-2C	28.9	121.3	74.4	54.4	81	153	29	57.90
X970108-2C	26.8	117.8	74.7	56.7	88	149	31	56.92
X970161-2L	28.9	114.1	74.4	47.0	91	149	31	60.36
X970161-3L	31.8	110.6	77.5	48.9	86	149	31	60.21
X970163-3	29.1	101.3	78.1	52.1	82	151	30	58.48
X970163-4C	29.6	102.6	78.1	53.2	93	153	30	58.43
X970167-1	28.6	100.7	78.9	44.8	91	147	29	59.33
X970170-2L	31.7	126.6	74.2	47.3	96	150	32	58.92
X970170L	32.1	104.3	79.6	50.0	90	150	30	59.69
X970184-1C	28.3	128.8	83.3	50.6	81	148	31	58.90
X970185-1C	26.3	121.9	80.7	48.5	87	151	30	57.90
Location Avg.	29.1	108.9	79.8	50.0	86.0			
CV	10.7	14.6	7.4	8.6	9.5			
$LSD_{(0.05)}$	3.6	18.2	6.9	5.1	9.6			

[a]Pullman, Washington yield data were reported for comparison.
[b]Heading date, height, and test weight data are the average over all locations.

Early heading dates and spring vegetative growth are important traits for varieties to be well adapted to northeastern Oregon. Experimental lines in the Oregon-Elite nursery averaged 3 days later than ‘Tubbs’ for heading dates, although line X970167-1 averaged the same, and lines X9602044-2C and X970184-1C averaged 1 day later than ‘Tubbs’ (Table 1). Cultivars that come out of dormancy early in the spring and start producing vegetative growth can help improve yields in northeastern Oregon. This trait is seen in many varieties grown in the region, such as ‘Tubbs’ and ‘Stephens’, and has been observed in some of the lines in the club nurseries like X970184-1C and X970185-1C. It is not a characteristic of lines adapted to Washington like ‘Xerpha’, ‘Madsen’, and ‘Eltan’. Lines are continually being screened and developed to have earlier heading dates and early spring growth, and more emphasis is being placed on developing varieties with these traits so that club wheat will compete with the leading soft white winter varieties in northeastern Oregon.

Coleoptile lengths from the advanced USDA-ARS club breeding lines measured an average of 3 inches. The longest coleoptile lengths were the checks ‘Moro’ and ‘Edwin’ at 4.4 and 4.5 inches, respectively. Lines ARS970170-2L and ARS970168-2C were next with coleoptile lengths of 3.4 and 3.2 inches, respectively (Fig. 1). The remaining experimental lines were similar to or greater than the check ‘Tubbs’ at 2.7 inches, and were about the same as ‘Bruehl’, ‘Chukar’, and ‘Eltan’, with lengths of 3.1, 3.0, and 2.9 inches, respectively. Using long-coleoptile varieties similar to ‘Edwin’ or ‘Moro’ in crosses could increase coleoptile length in breeding lines and improve deep seeding emergence. Selection for longer coleoptile length and emergence will be increased in importance in the USDA-ARS breeding program for 2009 and 2010.

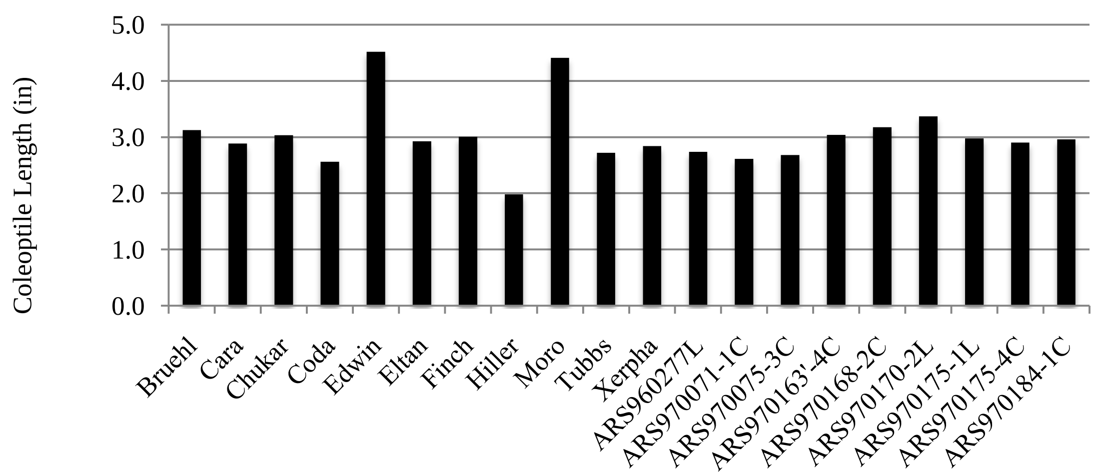

Figure 1. Average coleoptile length for check varieties and advanced USDA-ARS club breeding lines.

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Growing Canola on Wide Row Spacing

Don Wysocki and Nick Sirovatka

Abstract

The effect of row spacings and sowing rates were investigated on winter canola (*Brassica napus*) sown after summer fallow. Randomized complete block experiments with four replications using row spacings of 6, 12, 24, and 30 inches and seeding rates of 5 and 7 lb of seed/acre were sown with winter canola (cv 'Athena') on 14 September 2006 and 12 September 2007 and harvested 4 July 2007 and 15 July 2008, respectively. In 2007, yields for 6-, 12-, 24-, and 30-inch spacing averaged 2,835, 2,836, 1,675, and 1,635 lb/acre, respectively. In 2008, yields for these treatments were 2,904, 2,949, 2,794, and 2,370 lb/acre. Yield difference between years may be due to a cooler, longer growing season in 2008. In 2008, plots were combined 11 days later. Increasing sowing rate from 5 to 7 lb/acre increased yield in some row spacings by up to 8 percent and had no effect in other row spacings. Yield component measurements in 2008 showed that as row spacing increases plants compensate by increasing the number of branches (racemes) by up to 40 percent, number of pods per branch by up to 140 percent, and pods per plant by up to 200 percent. Plants compensate only slightly or none at all by increases in seed size or number of seeds per pod. Although plants per unit length of row increased with increases in row spacing, plants per unit area stabilized at 12-inch row spacing at about 4 to 5 plants/ft^2 and remained similar for wider spacings. Growing canola on row spacings as wide as 24 inches appears feasible if stands can be established in late August and early September.

Keywords: canola, plant compensation, row spacing, seeding rate, yield components

Introduction

Recent interest in oil seed crushing and biofuels has heightened interest in canola production. Stand establishment is the most difficult aspect of winter canola (*Brassica napus*) production in the Pacific Northwest (PNW). Large amounts of crop residues, dry soils, and wide diurnal temperature swings present challenges for stand establishment (Douglas et al. 1990). If canola can be established in the fall, a production niche exists in the low and intermediate rainfall areas of the PNW (Wysocki et al. 1991). In these areas the acreage of winter canola is limited by difficulty of stand establishment. Autumn conditions typically are hot and dry during the optimum sowing interval for canola, and the seed zone water is often marginal. Equipment and methods commonly used to plant wheat have been only marginally successful with canola. Unlike wheat, canola is a much smaller seed (90,000 to 120,000 seeds/lb) and cannot emerge as well from deep soil placement. It is best to plant canola shallow (less than 1 inch), but into firm, moist soil. A method that has been tried by innovative producers is to plant canola into cultivated fallow or chem-fallow using row spacings much wider than used for winter wheat. This allows wide shovel openers to move dry, surface soil to the areas between the rows and creates a seed row that is shallow to moist soil, allowing the seed to be placed relatively shallow with a minimum of soil cover. Wider rows have the potential to allow for better stand establishment, but may also have an adverse effect on yield. The effect of row spacing on yield of winter canola in the PNW has not been evaluated. To better understand the effect of row width and sowing rate on yield of winter canola, we conducted row width experiments in the 2006-2007 and 2007-2008 crop years.

Numerous studies have been conducted on row spacing of canola, but these have been mostly in areas of high rainfall and on spring-planted canola. These studies have generally focused on row spacing commonly used for planting cereals, but a few have looked at wider spacings. In Sweden, Ohlsson (1974) found that yields were lower when canola was grown on 18-inch spacing versus either 5- or 10-inch spacing. In Alberta, Canada, Kondra (1975) reported statistically similar yields for 6-, 9-, and 12-inch row spacing but lower yields with 24-inch spacing. A study by Clarke et al. (1978) in southern Saskatchewan, Canada, reported that canola grown at 12-inch row spacing yielded more than broadcast seeding at equivalent sowing rates. In northwestern Alberta, seed yield was 36 percent higher for canola grown at 3-inch row spacing than on 6- and 9-inch row spacing (Christensen and Drabble 1984). However this study found no effect between sowing rates of 3 and 6 lb/acre. Morrison et al. (1990) in Manitoba, Canada, showed that canola yield was greater from stands sown on 6- than on 12-inch spacing. In Ontario, Canada, May et al. (1993) found that row spacings of 4 and 8 inches did not influence yield or oil content of three spring canola cultivars but that yield did increase as sowing rate was increased from 1 to 8 lb/acre. Dosdall et al. (1998) found that flea beetle (*Phyllotreta crucifera*) damage was less when canola was grown at wider row spacings and higher seeding rates. Johnson and Hanson (2003) in North Dakota reported no difference in yield, oil content, date to flower, or lodging on four spring canola cultivars grown on 6- and 12-inch row spacing. In a drought-affected study in New South Wales, Australia, Haskin (2007) found no difference in yield of canola grow on 6- and 24-inch row spacing.

In summary, various studies in several locations over a 30-year period have shown that row spacing sometimes affects yield. Differences in climatic conditions, soil conditions, weed competition, planting date, stand establishment, and seed variables make direct comparison of these studies difficult. In those studies where row spacing was shown to affect yield, the difference in yield was attributed to combinations of weed competition, intra-species competition of plants along the row, or incomplete exploitation of available water and nutrients by rows being too wide. Winter canola in the PNW may be able to tolerate wider rows because of the long growing period. The growing season for winter canola in the PNW is nearly 10 months; this allows time for plants to branch more profusely, thus exploiting the wider rows. Wide rows could be an advantage for herbicide-tolerate canola, where weed competition can be eliminated.

Methods

The effect of row spacing and sowing rate on winter canola was investigated at the Columbia Basin Agricultural Research Center (CBARC) (45°10' N, 118° 34' W; elevation 1,500 ft) near Pendleton, in Umatilla County, Oregon. The soil at CBARC is a Walla Walla silt loam, coarse silty, mixed, mesic, hyperactive Typic Haploxerolls. Soil fertility levels for nitrogen (N), sulfur (S), and phosphorus (P) in the trial were adjusted for a seed yield goal of 2,700 lb/acre (et al. 2007a) by shank application of 80 lb N/acre as anhydrous ammonia and 10 lb S/acre as nitrosol during August. Annual grasses and volunteer wheat were controlled in the crop with a post-emergence application of 11 oz/acre Assure® II herbicide during November.

A randomized complete block experiment with four replications using factorial combinations row spacing of 6, 12, 24, or 30 inches and seeding rates of 5 or 7 lb seed/acre was sown with ‘Athena’ winter canola on 14 September 2006 and 12 September 2007. Plot dimensions were 5 by 40 ft. Plots were sown into tilled summer fallow that had been pre-irrigated with 1 inch of water 5 days before planting. The seedbed was prepared with one pass of a Brillion rolling harrow. Seed was sown 0.75 inches deep using a Hege plot drill equipped with double disk-openers and semi-pneumatic press wheels with depth control. The spinner distribution head on the drill was changed to sow the proper number of rows at the desired spacing. Table 1 shows the number of rows in each plot and the plot width. To achieve the proper spacing with neighboring rows outside the plot, plots on either side were sown in the proper position so that adjacent rows had the same spacing as the treatment.

Table 1. Winter canola row spacing, plot width, and number of rows per plot, Columbia Basin Agricultural Research Center, Oregon, 2007.

Row spacing (in)	Plot width (in)	Rows/plot
6	60	9
12	60	5
24	72	3
30	60	2

In both years of this study, plots were force lodged with a John Deere 880 swather equipped with a 5-ft-wide “pusher header” (Wysocki et al. 2007b). Plots were force lodged on 21 June in 2007 and on 7 July in 2008. These dates were considered first brown seed, which is the crop stage preferred for early swathing. (Wysocki et al. 1996). Plots were harvested with a Hege 140 plot combine with a 5-ft header equipped with auger feed and canola sieves on 4 July, 2007 and 15 July, 2008. Grain yield was determined by weighing harvested seed. Data on yield components of: 1) branches (racemes) per plant, 2) pods per plant, and 3) seed size (1,000 seed weight) were taken in 2008. Because yield component measurement is very time consuming, data was collected on only the treatments that had been sown with 5 lb seed/acre. Three representative plants from these treatments were selected immediately after pushing. Harvested plants were collected, dried, and taken to the laboratory. Racemes and pods per plant were counted. Pods were clipped from the plants, bulk threshed, and seed yield determined by weighing. Data were averaged from the selected plants. From these data, we derived yield components of seeds per raceme and seeds per pod. Pods per raceme were determined by dividing pods per plant by racemes per plant. Seeds per pod were determined using threshed seed weight from sampled plants, pods per plant, and 1,000 seed weight values. Seed weight was determined from three random 1,000-seed counts taken from harvested seed from each plot.

Stand counts were taken for all treatments, both 5 lb/acre and 7 lb/acre sowing rate, on two 3.3-ft-long row lengths in each plot after harvest. Plant stems in each row section were counted. Plants per linear foot of row and plants/ft^2 were computed using the average of the two row section elements.

Results

Yields of winter canola at four row spacings and two sowing rates for 2007 and 2008 are presented in Table 2 and Figure 1. In 2007, yields at 6- and 12-inch row spacing were significantly higher than yields obtained from 24- and 30-inch row spacing. Row spacing of 24 and 30 inches yielded about 1,000 lb less per acre or only 60 percent of the narrower spacings. In 2008, 6-, 12- and 24-inch row spacings yielded nearly the same and 30-inch row spacing yielded about 300 lb/acre less, or about 85 to 90 percent of the other row spacing. Yields did not differ significantly among row spacing for the 5 lb/acre sowing rate, but did differ among the two narrowest spacings at both sowing rates and the widest spacing at the 7-lb/acre sowing rate.

Table 2. Yield and plant stand of winter canola at various row spacings and sowing rates, Columbia Basin Agricultural Research Center, Pendleton, Oregon, 2007 and 2008.

Treatment		Yield 2007		Yield 2008		Plant stand 2008	
row spacing	seeding rate	lb/acre	percent of highest yield	lb/acre	percent of highest yield	plants/ft of row	plants/ft^2
In	Lb/ac						
6	5	2,757a	95	2,830ab	89	4.4d	8.8a
6	7	2,912a	100	2,977a	94	4.4d	8.9a
12	5	2,893a	99	2,719ab	86	4.5d	4.5c
12	7	2,780a	95	3,179a	100	7.1c	7.1b
24	5	1,725b	59	2,796ab	88	8.8bc	4.4c
24	7	1,625b	56	2,792ab	88	7.8c	3.9c
30	5	1,521b	52	2,311b	73	10.6bc	4.3c
30	7	1,749b	60	2,427b	76	13.3a	5.3c
LSD(0.05)		621		538		2.6	1.7

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

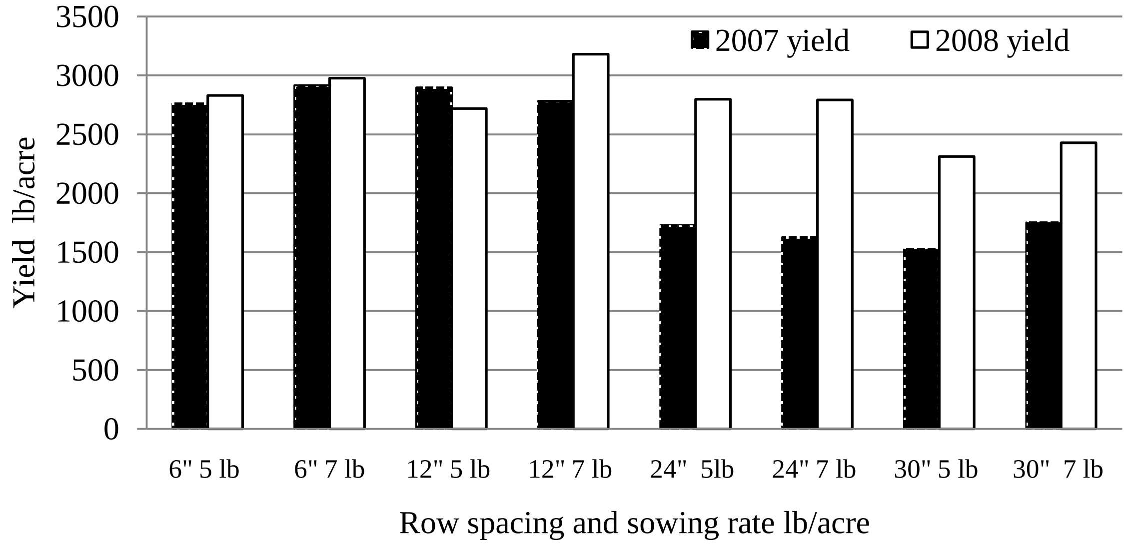

Figure 1. Yield of winter canola planted at four row spacing and two sowing rates, Columbia Basin Agricultural Research Center, Pendleton, Oregon, 2007 and 2008.

Data on plant stand for 2008 are presented in Table 2 and Figure 2. As might be expected, plant stand along the row and per unit area changed with row spacing and sowing rate. Plants/ft for 6-inch row spacing at both sowing rates were nearly double those in rows more widely spaced. Plants/ft^2 at 12-, 24-, and 30-inch row spacing were 4 to 5 plants/ft^2. The exception was 7.1 plants/ft^2 at 7 lb seed/acre on 12-inch row spacing.

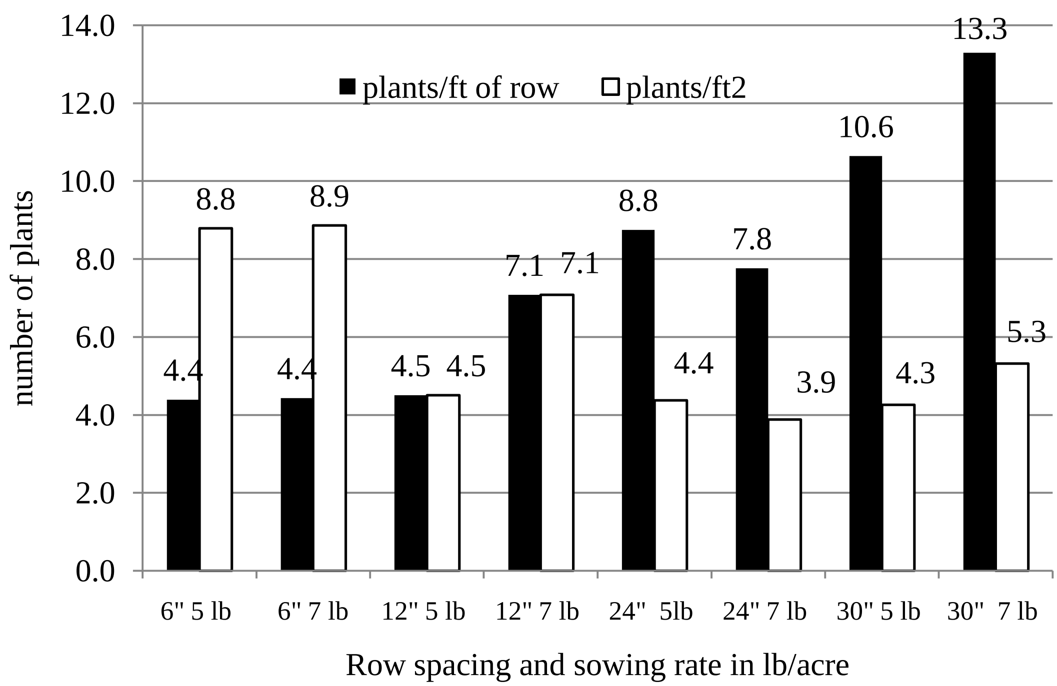

Figure 2. Effect of four row spacings and two sowing rates of winter canola on plants/ft of row and plants/ft2, Columbia Basin Agricultural Research Center, Pendleton, Oregon, 2008.

Yield component data are presented in Table 3 and Figure 3. Branching (racemes/plant), pods per plant, and pods per raceme increased as row spacing increased. Seed size (1,000 seed weight) and seeds per pod were fairly uniform for all row spacings (Fig. 3).

Table 3. Yield components of winter canola for various row spacings all sown at 5 lb seed/acre, Columbia Basin Agricultural Research Center, Pendleton, Oregon, 2008.

Row spacing (in)	Racemes/plant	Pods/plant	Pods/raceme	1,000 seed weight (g)	Seeds/pod
6	5.5b	152b	27.7b	4.7a	5.1a
12	5.5b	190b	34.1b	5.0a	4.9a
24	6.5ab	237ab	36.5ab	4.9a	5.1a
30	7.6a	310a	40.6a	5.1a	5.9a
LSD (0.05)	1.7	86	10.6	0.5	0.9

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

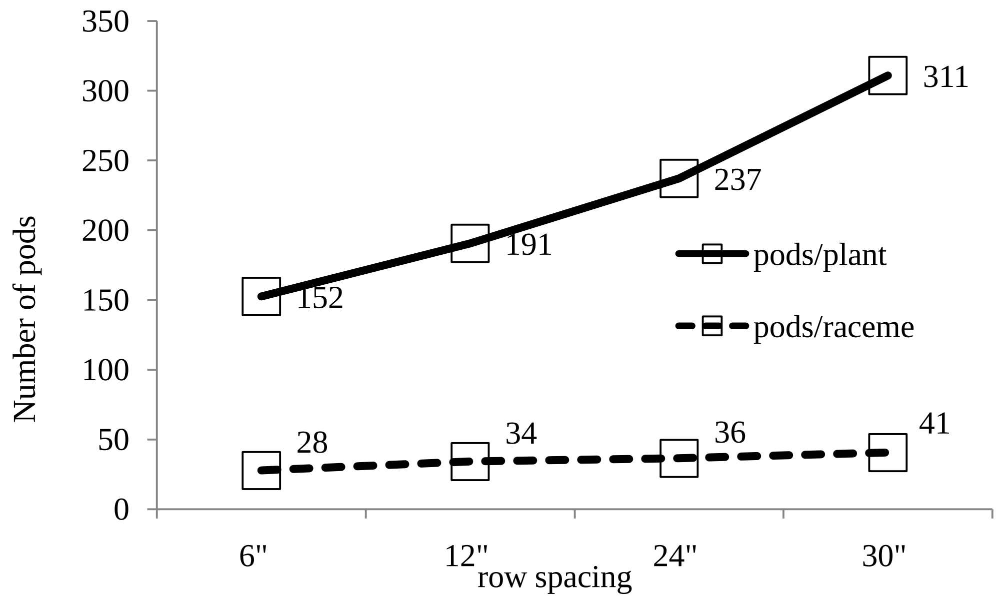

Figure 3. Effect of row spacing on number of pods per plant and per raceme of winter canola, Columbia Basin Agricultural Research Center, Pendleton, Oregon 2008.

Discussion

Yields in 2007 and 2008 are somewhat contrasting (Table 2 and Fig. 1). In 2007, the best yielding treatment was the 6-inch row spacing with 7 lb/seed acre; 24- and 30-inch row spacings yielded only 52 to 60 percent of this. In 2008, the highest yielding treatment was 12-inch row spacing with 7 lb seed/acre; the wider spacings yielded 73 to 88 percent of this yield (Table 2). One possible reason for the reduced effect of row spacing in 2008 compared to 2007 is that the 2008 growing season was cooler and had more late-season rain. This may have allowed plants in wider rows to compensate better than in 2007. In 2008, yields for both sowing rates at 6-inch spacing were 89 and 94 percent of the highest yield. Stand counts showed that plant density was nearly 9 plants/ft^2 on these treatments. It is possible that these densities were high enough to cause competition among plants, which limited yield.

As expected, plant stands along the row (plant/ft of row) increased as row spacing and seed rate increased. However, seedling success actually decreased. If seedling success remained constant with row spacing, then plants/ft of row at 6-inch spacing should increase by 2, 4, and 5 times with 12-, 24-, and 30-inch row spacing, respectively. Based on the measured seed weight of 92,000/lb of 'Athena' seed used in this study, at 5 lb seed/acre the planting density in seeds/ft of row for 6-, 12-, 24-, and 30-inch row spacing is about 5, 10, 20, and 25 seeds, respectively. Comparing these numbers to data in Table 2, the seedling success declined from about 80 to 50 to 40 to 35 as the row width increased from 6 to 12 to 24 to 30 inches. Regardless, the stands yielded well.

Yield component data showed that canola plants compensated for increased row spacing by branching more and by increasing both the number of pods per plant and pods per raceme. Canola plants did not significantly increase 1,000 seed weight (seed size) or seeds per pod to compensate.

Conclusion

Growing canola using wide row spacing appears to be feasible, if stands can be established in late August and early September. Over the 2 years of this study, highest yields were obtained by planting on 6- or 12-inch row spacings. However, yield for planting on 24-inch rows was statistically the same as for narrow rows in the second year of this study. Given the mixed performance of the 2 years of this study, if stand establishment can only be successful by using wide spacing, then the preferable row width is 24 rather than 30 inches. Sowing rates of 5 lb/acre produced suitable stands of winter canola when sown early. Sowing rates above 5 lb/acre are not recommended, unless planting after September 20th.

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Phosphorus Fertilization of Late-Planted Winter Wheat after Chemical Fallow

Larry Lutcher, William Schillinger, Don Wysocki, Stewart Wuest, and Neil Christensen

Abstract

Winter wheat (*Triticum aestivum* L.) is planted in low precipitation areas of the Columbia Plateau after 14 months of fallow. Tillage is conducted during the fallow period to retain seed-zone moisture and control weeds. Chemical fallow is an alternative to the tillage-based method. The disadvantage of chemical fallow is the loss of seed-zone moisture and inability to plant early. Delayed plant growth and reduced grain yield associated with late planting may be offset by phosphorus fertilization. We conducted field trials to evaluate effects of 0, 10, and 30 lb P_2O_5/acre on P nutrition, plant growth, yield components, and grain production. Soft white winter wheat was planted into chemical fallow during the third week of October. Phosphorus fertilizer was placed below-and-beside the seed while planting. Phosphorus rate effects were dependent on P supply in the soil. Application of 30 lb P_2O_5/acre improved P uptake, dry matter accumulation, spikes per unit area, and grain yield at sites where initial soil test P levels were less than (<) 12 ppm. Response to P fertilizer was apparent at other sites where initial soil test P levels were greater than (>) 12 ppm and root injury may have been caused by crown rot pathogens (*Fusarium pseudograminearum* and *Fusarium culmorum*) or carryover effects of sulfentrazone.

Key words: chemical fallow, dry matter, grain yield, late planting, low precipitation zone, phosphorus fertilizer, phosphorus uptake, winter wheat

Introduction

Winter wheat is planted in low precipitation areas of Oregon and Washington after 14 months of fallow. Tillage is used in the spring of the fallow period to establish a low bulk density soil mulch that retains moisture in the seed-zone. Subsequent tillage operations maintain the mulch and control weeds. The tilled fallow system allows for early (late August-to-mid September) planting with deep-furrow drills and the production of maximum yield. Chemical fallow is an alternative to the tillage-based method. Optimism about chemical fallow is tempered by yield reductions that are a consequence of late planting (Donaldson et al. 2001). Late planting in October, or after the onset of fall rains, is necessary because seed-zone moisture during early planting dates is frequently less than that required for uniform germination and emergence (Oveson and Appleby 1971, Lindstrom et al. 1974, Hammel et al. 1981, Schillinger and Bolton 1993).

Yield reductions from late planting may be offset, to some extent, by phosphorus (P) fertilization. Yield response to P fertilizer is presumed to be the effect of P uptake, or accelerated dry matter accumulation early in the growing season (Sutton et al. 1983), and a related increase in spikes per unit area (SPU) (Black 1982, Sander et al. 1991, Sander and Eghball 1999). Our objective was to evaluate these effects in a low-rainfall, chemical fallow system.

Materials and Methods

Field trials were conducted at three locations during the 2003-2004, 2004-2005, and 2005-2006 crop years. These locations will hereafter be referred to as the north, south, and southeast regions. North region field trials, or sites, were on the Washington State University (WSU) Dryland Research Station near Lind in Adams County. Sites in the south region were established on a farm in Morrow County, Oregon. Southeast region sites were in Umatilla County, Oregon on privately-owned land leased by the USDA-ARS. Soils are mapped as either a Ritzville silt loam (coarse-silty, mixed, superactive, mesic Calcidic Haploxeroll) or Shano silt loam (coarse-silty, mixed, superactive, mesic Xeric Haplocambid). These closely-related soils formed in wind-blown loess on uplands or terraces and have chemical and physical properties representative of 3.85 million dry-farmed acres on the Columbia Plateau. Average, annual precipitation ranges from 8-to-12 in.

Soft white winter wheat was planted into undisturbed chemical fallow during the third week of October. 'Tubbs' and 'Stephens' were grown in the south and southeast region, respectively. 'Eltan' was grown in the north region. The planting rate was approximately 24 seeds/ft^2. Planting was accomplished using a customized Fabro® plot drill equipped with narrow hoe-type openers (Fabro Enterprises Ltd., Swift Current Saskatchewan) on 12-in row spacing, or a Cross-Slot® drill equipped with notched, coulter disc openers (Baker No-Tillage, Ltd., Fielding, New Zealand) on 8-in spacing.

The Cross-Slot® drill was used at 2003-2004 and 2004-2005 sites in the north region. The Fabro® drill was used at all other (seven) sites. Treatments consisted of three P application rates (0, 10, and 30 lb of phosphate (P_2O_5)/acre) applied to plots in a randomized complete block (RCB) design with four replications. Phosphorus fertilizer, banded below-and-beside the seed, was applied through the Fabro® drill as concentrated (triple) super phosphate (0-45-0). Urea (46-0-0) was applied simultaneously with P and at a uniform rate across treatments. Ammonium polyphosphate (10-34-0) and Solution 32 were used with the Cross-Slot® drill.

Effective weed control during the fallow cycle was accomplished using a late-fall tank mix application of glyphosate plus a water dispersible, granular formulation of sulfentrazone. A second glyphosate application in March or April was used to control broadleaf weeds and downy brome (*Bromus tectorum*) or volunteer wheat that emerged after the initial (late-fall) application. Glyphosate was applied in the fall and spring at a rate of 0.38 lb ae/acre. Spot applications of glyphosate were used at some sites to control localized populations of prickly lettuce (*Lactuca serriola*) and/or marestail (*Conyza canadensis*). Spot applications were conducted in August. In-crop weed control was accomplished by applying labeled rates of bromoxynil + MCPA when wheat was tillering and weed species were small and actively growing.

Initial soil test P levels (Table 1) were determined from samples (0-to-12 in depth) collected in September. Sixteen soil samples from each site were combined into four composite samples. Composited samples were air-dried before extraction and analysis (Olsen et al. 1954).

Sampling for plant P concentration and dry matter occurred in mid-to-late April when the first node on the main stem of wheat plants was detectable just above the soil surface. Plants were cut at ground level, placed in paper bags, and dried at 150º F for several days. Plant P concentration was determined using a dry ash by ICP-AES procedure (Gavlak et al. 1994). Dry matter was quantified by weighing oven-dried plant samples on a digital scale with 0.01-g accuracy. Measurement of spikes per unit area, conducted just before grain harvest in mid-to-late July, was accomplished by counting the number of spikes along 3-ft of row. Wheat was harvested using a small-plot combine equipped with a 5-ft cutting platform. Harvested grain was weighed and yield was calculated after adjustment to10 percent moisture.

Data were scrutinized for sources of variation using the Statistix® 8 general AOV/AOCV option (Analytical Software, 2006) for a balanced, equally replicated RCB design. Phosphorus rate effects were evaluated using a "protected" least significant difference test.

Results and Discussion

Growing conditions

The quantity and timing of precipitation (Fig. 1) and accumulation of growing degree-days (data not shown) varied over the duration of the project, but year-to-year trends were consistent among regions (Fig. 2). Average, annual precipitation during the first, second, and third crop year was 11.0, 7.2, and 13.3 in, respectively. Average, annual precipitation in the north region (9.0 in) was less than that measured in the south (11.0 in) and southeast region (11.5 in).

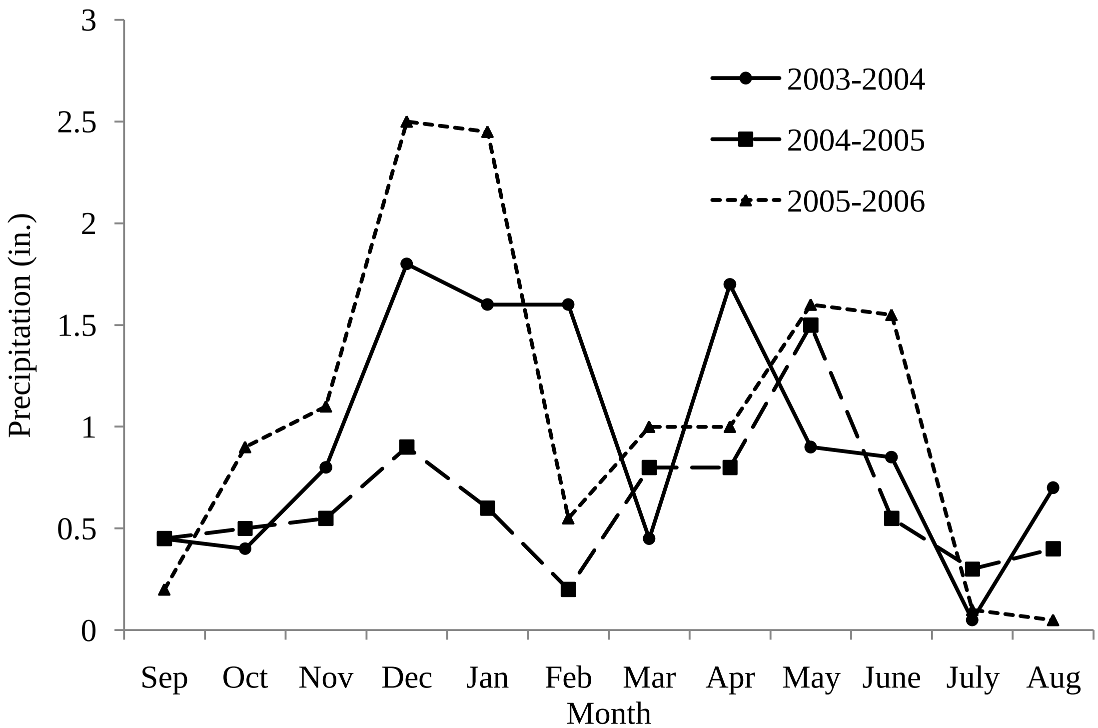

Figure 1. Average monthly precipitation for the years 2003-2004 to 2005-2006.

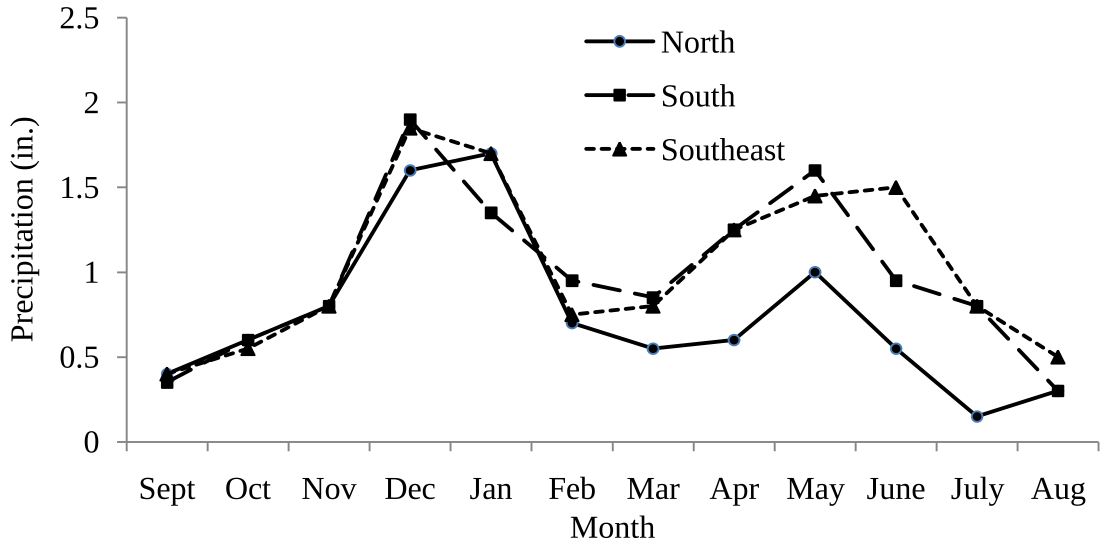

Figure 2. Average regional monthly precipitation for north, south, and southeastern trial sites.

Phosphorus rate effects

Phosphorus rate effects were dependent on P supply in the soil. Results in subsequent paragraphs of this report apply to sites where soil test P (STP) levels were either less than or greater than 12 ppm (Table 1).

Table 1. Initial soil test P (STP) levels for sites in the north, south, and southeast region, by year.

Region	2003-2004	2004-2005	2005-2006
	------------------	STP level (ppm P)†	------------------
North	14.3	12.1	11.1
South	9.4	8.7	11.7
Southeast	6.8	16.1	13.5

† Sodium bicarbonate ($NaHCO_3$) extractable P values for samples (0 to 12 in depth) collected before planting.

The 30 lb P_2O_5/acre rate increased plant P concentration, dry matter, and P uptake at five sites where STP levels were less than 12 ppm (Table 2). The 30 lb P_2O_5/acre treatment had a similar effect on SPU and grain yield (Table 3).

Table 2. Phosphorus rate effects on plant P concentration (PPC), dry matter, and P uptake in winter wheat.[†] Data are averages from five sites where STP levels were < 12 ppm.

P rate	PPC	Dry matter	P uptake
(lb P_2O_5/acre)	(% P_2O_5)[§]	(lb/acre)[§]	(lb P_2O_5/acre)[§]
0	0.57 a	1,679 a	9.6 a
10	0.59 a	1,896 b	11.2 a
30	0.66 b	2,165 c	14.3 b

[†] Plant samples collected in mid-to-late April when the first node on the main stem of wheat plants was detectable just above the soil surface.
[§] Unique letters within columns indicate a statistically significant difference ($P \leq 0.05$).

Table 3. Phosphorus rate effects on spikes per unit area (SPU) and grain yield. Yield response is percent increase over the control. Data are averages from five sites where STP levels were < 12 ppm.

P rate	SPU[†]	Grain yield[†]	Yield response
(lb P_2O_5/acre)	(spikes/ft^2)	(bu/acre)	(%)
0	9.5 a	49.1 a	-----
10	10.7 b	50.5 a	2.9
30	11.5 c	52.4 b	6.7

[†] Unique letters within columns indicate a statistically significant difference ($P \leq 0.05$).

During the planning stages of this project, we assumed that 30 lb P_2O_5/acre would be more than enough to realize maximum yield. The linear response to increasing rates of P fertilizer, at sites where the initial STP level was less than 12 ppm (Fig. 2), indicates this assumption may have been incorrect. However, it is important to note that yield increases were relatively small and may not be economical.

The 10 and 30 lb P_2O_5/acre rate had a positive effect on plant P concentration, dry matter and/or P uptake at four sites where STP levels were greater than 12 ppm (Table 4).

Table 4. Phosphorus rate effects on plant P concentration (PPC), dry matter, and P uptake in winter wheat.[†] Data are averages from four sites where STP levels were > 12 ppm.

P rate	PPC	Dry matter	P uptake
(lb P_2O_5/acre)	(% P_2O_5)[§]	(lb/acre)[§]	(lb P_2O_5/acre)[§]
0	0.62 a	1,124 a	7.0 a
10	0.65 b	1,222 a	7.9 b
30	0.66 b	1,386 b	9.1 c

[†] Plant samples collected in mid-to-late April when the first node on the main stem of wheat plants was detectable just above the soil surface.
[§] Unique letters within columns indicate a statistically significant difference ($P \leq 0.05$).

Grain yield response, compared to the control, was also evident (Table 5), but the effect of 10 and 30 lb P_2O_5/acre rates was statistically similar. This is an important concept. Our research shows that accelerated early-season growth and development (dry matter), in fields where STP levels were greater than 12 ppm, may not necessarily translate to a corresponding improvement in yield.

Table 5. Phosphorus rate effects on spikes per unit area (SPU) and grain yield. Yield response is percent increase over the control. Data are averages from four sites where STP levels were > 12 ppm.

P rate	SPU[†]	Grain yield[†]	Yield response
(lb P_2O_5/acre)	(spikes/ft^2)	(bu/acre)	(%)
0	7.3 a	35.2 a	-----
10	8.1 ab	37.7 b	7.1
30	8.6 b	38.5 b	9.4

[†] Unique letters within columns indicate a statistically significant difference ($P \leq 0.05$).

The response curve for sites where STP levels were greater than 12 ppm (Fig. 3) is note-worthy. Grain yield response exceeded that at sites where STP levels were less than 12 ppm. These results are contradictory to what is normally observed and may be a consequence of root injury caused by crown rot pathogens (*Fusarium pseudograminearum and Fusarium culmorum*) or carryover effects of sulfentrazone—a soil residual herbicide used to control Russian thistle (*Salsola iberica*) in chemical fallow. A 14 percent yield response to the 30 lb P_2O_5/acre rate was evident in the north region during 2004-2005. Fusarium crown rot pathogens are known to exist in soil at this location. A chocolate-brown discoloration of stems just above the crown of plants, apparent in 2004-2005, was evidence of infection (Smiley et al. 2005). A 10.3 percent response to the 10 lb P_2O_5/acre rate was observed in the southeast region (2005-2006) where crop injury was obvious. Above-ground crop injury may have been caused by the accumulation of sulfentrazone in the root-zone. Suspected carryover effects occurred during a year when the quantity of post-application rainfall was much greater than the long-term average. Applied P, in this case, may have lessened the deleterious effects of sulfentrazone (Dayan et al. 1996, Dayan et al. 1997, Li et al. 1999) in a manner similar to that reported for plants stressed by root pathogens (Cook et al. 2000).

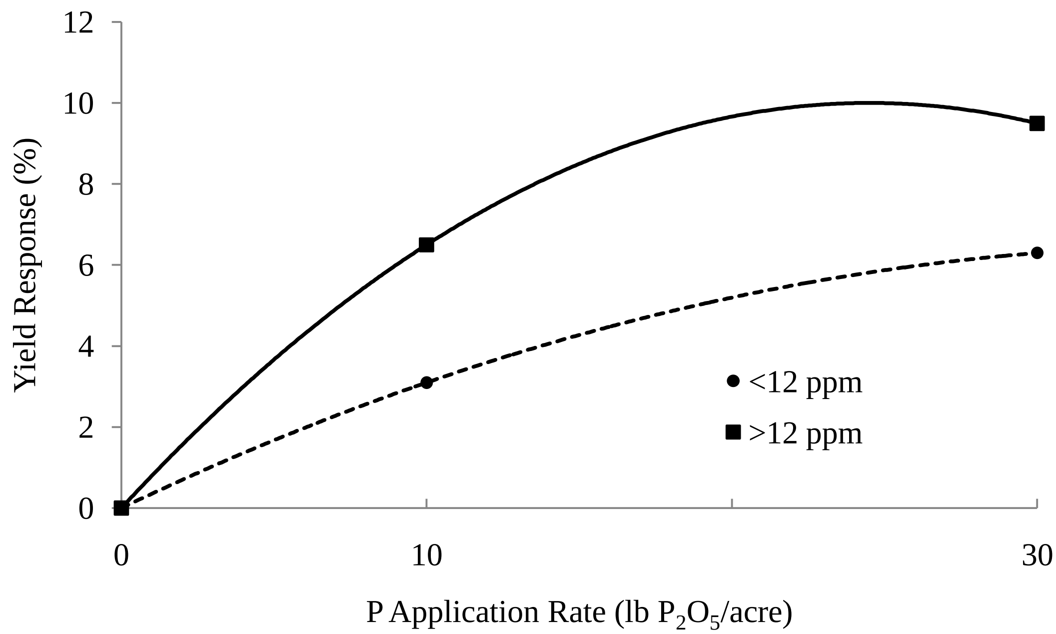

Figure 3. Effect of P application rates on grain yield response (percent increase over the control). Data are averages from sites where STP levels were either less than or greater than 12 ppm.

Summary

Phosphorus application increased plant P concentration, dry matter, and P uptake. Application of 30 lb P_2O_5/acre at locations where STP levels were < 12 ppm improved grain yield by 6.7 percent. The advantages of P applied during planting, and in a localized zone below the seed, should be considered when fertilizer prices are favorable and STP levels are < 12 ppm.

Grain yield response to fertilization at locations where STP levels were > 12 ppm was limited to situations where root injury may have been caused by Fusarium crown rot pathogens or carry-over effects of sulfentrazone. Suspected root injury cannot be confirmed by data collected from this experiment. Future efforts to evaluate effects of P fertilization should include methods to quantify the source and extent of root damage.

Acknowledgments

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Probability of Rain in September and October at Moro, Oregon

Karl Rhinhart, Erling Jacobsen, and Steve Petrie

Abstract

Seeding at the optimum time is one key to producing the greatest yield of any crop. Successful seeding of winter wheat and other crops is predicated on having sufficient moisture in the seedzone to foster rapid germination and emergence. The objective of this work was to estimate the likelihood of receiving sufficient rainfall to bring about consistent germination. We searched the weather records for crop years 1929 through 2008 inclusive for the Sherman Station- Columbia Basin Agricultural Research Center (CBARC) to determine the likelihood of receiving 0.4-0.6, 0.6-0.8, and >0.8 inches of rainfall within 3, 5, or 7 days in September and October. Conditions in September were infrequently optimum for seeding; there was 0.8 inch of rain or more within 3 days in only 7 of 80 years. There were only 8 of 80 years when more than 0.8 inch of rainfall fell within 7 days. We found only 34 years out of 80 in which 0.4-0.6 inch of rainfall occurred within 7 days, the minimum we determined to be adequate to promote germination. We also used the information to develop graphs that show the cumulative probability of receiving 0.4-0.6, 0.6-0.8, or more than 0.8 inch of rain in 3, 5, or 7 days for any date in September and October. For example, by September 20th, there is about 5 percent chance of having received more than 0.8 inch of rain within 3 days and about 10 percent chance of having received 0.6-0.8 inch of rain within 3 days.

Keywords: alternate crops, fallow, precipitation, seeding date, soil moisture, winter wheat.

Introduction

Seeding at the optimum time is one key to producing the greatest yield of any crop. Seeding winter wheat or other fall-seeded crops at the optimum time permits the crop to become established in the fall; it reduces the chance of winter injury and increases the yield potential. The optimum seeding date varies for different crops; optimum seeding date for winter wheat is a balance between having adequate seed zone moisture following summer fallow and the increased incidence of diseases such as Cephalosporium stripe and Fusarium crown rot that can occur with early seeding of winter wheat (Meister 1993). In the higher rainfall areas around Pendleton, Oregon the optimum seeding date for winter wheat is generally considered to be late September to early October, depending on the specific location. Seeding earlier can markedly increase disease incidence in the intermediate and high rainfall regions. However, in lower rainfall regions such as around Moro, Oregon early seeding is often necessary to be able to place the seed in moist soil. Later seeding can reduce the yield potential because the plants accumulate fewer growing degree days before they mature and they mature later in the summer when they are more likely to experience water stress.

Some crops, such as canola, require earlier seeding than winter wheat. Canola does best when seeded by September 20 (Wysocki et al. 1991, 1992) because seedlings have time to grow to sufficient size to avoid winter injury. B. Brown (personal communication) indicated that canola should have four true leaves in the fall to avoid winter injury. The optimum seeding date for other potential alternative crops is unknown but will be an important factor in their ultimate success or failure in dryland cropping systems.

Fall seeding in dryland agriculture is driven by the availability of adequate moisture in the seed zone. Seed placed in dry soil will not germinate; soil moisture must be at least 11 percent on a weight basis for the seed to imbibe (take up) water and to begin the germination process. Water uptake, or imbibitions, is more consistent and germination is more uniform and rapid if the soil has at least 13 percent moisture.

The timing and amount of fall rain affects other crop production practices in addition to crop seeding date. Early fall rain leads to the germination of downy brome (*Bromus tectorum)*, jointed goat grass (*Aegilops cylindrica*), volunteer cereals, and other winter annual plants that can then be controlled by herbicides or tillage. This in turn reduces the "green bridge" effect and reduces the severity of Rhizoctonia root rot (Veseth 1992).

Daily weather data have been recorded since the fall of 1929 and we recently completed entering all this data into an electronic database that permits easy access to daily, monthly, and seasonal weather data. Information currently collected includes daily precipitation, maximum and minimum air temperature, wind run and direction, pan evaporation, maximum and minimum water temperature, and soil temperature at 1-, 4-, and 8-inch depth. Not all weather data were collected since 1929 but we have a complete database for daily precipitation and air temperature.

Questions about the likelihood and timing of rain have arisen from many quarters including farmers, researchers, and risk analysts. The objective of our research was to determine the likelihood of various amounts of rainfall in September and early October that would permit successful fall seeding and crop establishment. Such information can be used in the decision-making process when evaluating potential alternative crops or for other uses.

Materials and Methods

Climate data, including daily precipitation, have been collected at the Sherman Station since the fall of 1929. Instrumentation consists of standard National Weather Service Cooperative Program instruments that are calibrated and serviced twice yearly by the local National Weather Service Office at Pendleton. During the winter of 2008-2009 we converted paper-based weather records into a comprehensive electronic database that permits us to readily search the database for the frequency of specific weather conditions. We searched the database for occasions in September and October when the rainfall total was 0.4-0.6, 0.6-0.8, and >0.8 inch within 3, 5, or 7 days. We used an "expansive" search query to find periods that ended on the first day or started on the last day of the search period.

Results and Discussion

The soil surface following fallow is air dry and there is insufficient moisture for seed germination. The depth of the "dust-mulch" layer on the soil surface will vary depending on the depth of rodweeding in a tillage-based fallow system but is usually about 4 to 6 inches deep. The depth to the moist soil in a chemical fallow system is more variable, both from field to field and within a given field, but typically ranges from 6 to 9 inches. The amount of moisture needed to wet the dry soil to the minimum moisture necessary to bring about germination is determined by the moisture content of air-dry soil, the minimum moisture content necessary for seed germination, the depth to which the soil must be moistened, and the weather conditions prior to and immediately following the rainfall.

The soil in the dust mulch layer has about 4 percent moisture by weight and the minimum soil moisture for germination is 11 percent (Schillinger and Young 2004), although germination is more uniform and rapid at 13 percent moisture. We will assume that the soil will be wetted from 4 to 13 percent so that the germination is more regular and the stand will be uniform. We will further assume that the dust mulch layer is 5 inches thick. Finally, we will assume that the dust mulch layer is “fluffed up” by tillage and the bulk density is less than normal. The bulk density of the surface of a Walla Walla silt loam soil ranges from 1.1 to 1.3 (Umatilla County Soil Survey) so we will use a value of 1.2 in our calculations. We will take the bulk density of the dust mulch layer to be 1.0. A minimum of 0.45 inches of moisture is required to completely wet the dust mulch layer and increase the water content from 4 to 13 percent. If the dust mulch layer is thicker than 5 inches, then more moisture is required and less moisture is needed if the dust mulch layer is less than 5 inches thick.

The moisture line in a chemical fallow field is more variable than in a tillage fallow field and is generally deeper. However, the same amount of moisture will wet the soil deeper in a chemical fallow situation where the soil has not been “fluffed up” by tillage.

The amount of rainfall needed for the surface soil to become moist to the moisture line is greater than the minimum amount of rainfall because of evaporative losses. Evaporative losses are minimized when conditions are cool, overcast, and the wind is calm. Conversely, evaporative losses can be substantial if the conditions following the rain are hot, sunny, and windy. Inspection of the weather records shows many cases where the potential evaporative loss the day after a rain exceeded the amount of the rainfall. Thus, the actual amount of rainfall needed to wet the soil to the moisture line is usually greater than the minimum of 0.45 inch.

Eastern Oregon is characterized by low intensity rainfall events with daily rainfall amounts rarely exceeding 0.5 inch in September and October. Of the 4,849 days in September and October between crop year 1929 and crop year 2008, 854 days or 17.6 percent had precipitation of 0.01 inch or greater. Only 0.8 percent of the days had rain that exceeded 0.50 inch; only 4.6 percent of the rainy days exceeded 0.50 inch of rain. Thus, it is usually necessary for two or more rainfall events to occur close together for the total rainfall to exceed the minimum amount needed to wet the surface soil.

We assumed that 0.4 to 0.6 inch of rainfall was barely adequate to wet the surface soil unless the dust mulch layer was unusually thin. Germination from this amount of rainfall is likely to be uneven and slow, especially if the soil has been disturbed by tillage or seeding, which results in evaporation losses. Rainfall of 0.6 to 0.8 inch is probably adequate to wet the surface soil and bring about good conditions for germination, and more than 0.8 inch of rainfall is almost always adequate to wet the surface soil and result in good germination. We considered how often the various amounts of rainfall fell within 3, 5, or 7 days. This represents a range of conditions from unlikely to be sufficient (0.4 to 0.6 inch in 7 days) to almost certainly adequate to moisten the surface soil (more than 0.8 inch in 3 days). We examined the month of September to determine the likelihood of being able to successfully seed in September and we also examined the period from September 1 to October 15.

Conditions in September were infrequently optimum for seeding. There was 0.8 inch of rain or more in 3 days in only 7 of 80 years (Table 1). There were only 8 of 80 years when we received more than 0.8 inch of rainfall in 7 days. Even when we examined the frequency of 0.4 to 0.6 inch of rainfall in 7 days, a condition not likely to lead to adequate soil moisture for germination, we found only 34 years out of 80 in which this minimal amount of rainfall occurred. Using 0.6 to 0.8 inch of rain in 5 days as a realistic minimum to moisten the surface soil sufficiently, we found only 16 of 80 years in which this occurred. The likelihood of being able to seed successfully by September 30 depends on factors other than simply rainfall; wind, temperature, and cloud cover all markedly affect the evaporative demand and hence, the effectiveness of the rainfall. Nonetheless, these data show that there is at best a 43 percent chance of being able to successfully seed a crop by September 31. Using more conservative assumptions, these data show only a 20 percent chance of being able to seed in September.

We also examined the period from September 1 to October 15 to cover the period of optimum seeding for winter wheat at Moro. The likelihood of sufficient rainfall for germination increased for all categories (Table 2). The number of years in which the rainfall exceeded 0.8 inch in 3 days increased from 7 to 12 and there were 18 years in which rainfall exceeded 0.8 inch in 7 days. There were 26 years (33 percent) in which 0.6 to 0.8 inch of rain fell in 5 days, a realistic minimum to permit seeding.

Table 1. Occurrence and probability of various amounts of rainfall in September at Moro, Oregon.

Amount of rainfall	In 7 days		In 5 days		In 3 days	
	# in 77 yr	-- % --	# in 77 yr	-- % --	# in 77 yr	-- % --
0.4 – 0.6 inches	34	43	29	36	22	28
0.6 – 0.8 inches	18	23	16	20	12	15
> 0.8 inches	8	10	7	9	7	9

Table 2. Occurrence and probability of various amounts of rainfall from September 1 to October 15 at Moro, Oregon.

Amount of rainfall	In 7 days		In 5 days		In 3 days	
	# in 77 yr	-- % --	# in 77 yr	-- % --	# in 77 yr	-- % --
0.4 – 0.6 inches	47	59	42	53	33	41
0.6 – 0.8 inches	29	36	26	33	19	24
> 0.8 inches	18	23	12	15	12	15

We also used the information to develop graphs that show the cumulative probability of receiving 0.4 to 0.6, 0.6 to 0.8, or more than 0.8 inch of rain within 3, 5, or 7 days (Figs. 1- 3). The vertical lines on the graphs are placed at September 30 and October 15. By examining the appropriate figure, the cumulative likelihood of receiving various amounts of rainfall can be estimated for any date. This information is useful to determine the likelihood of being able to successfully seed a crop into moist soil and have it sufficiently developed to withstand winter injury. For example, by September 20th, there is about 5 percent chance of having received more than 0.8 inch of rain within 3 days and about 10 percent chance of having received 0.6-0.8 inch of rain within 3 days.

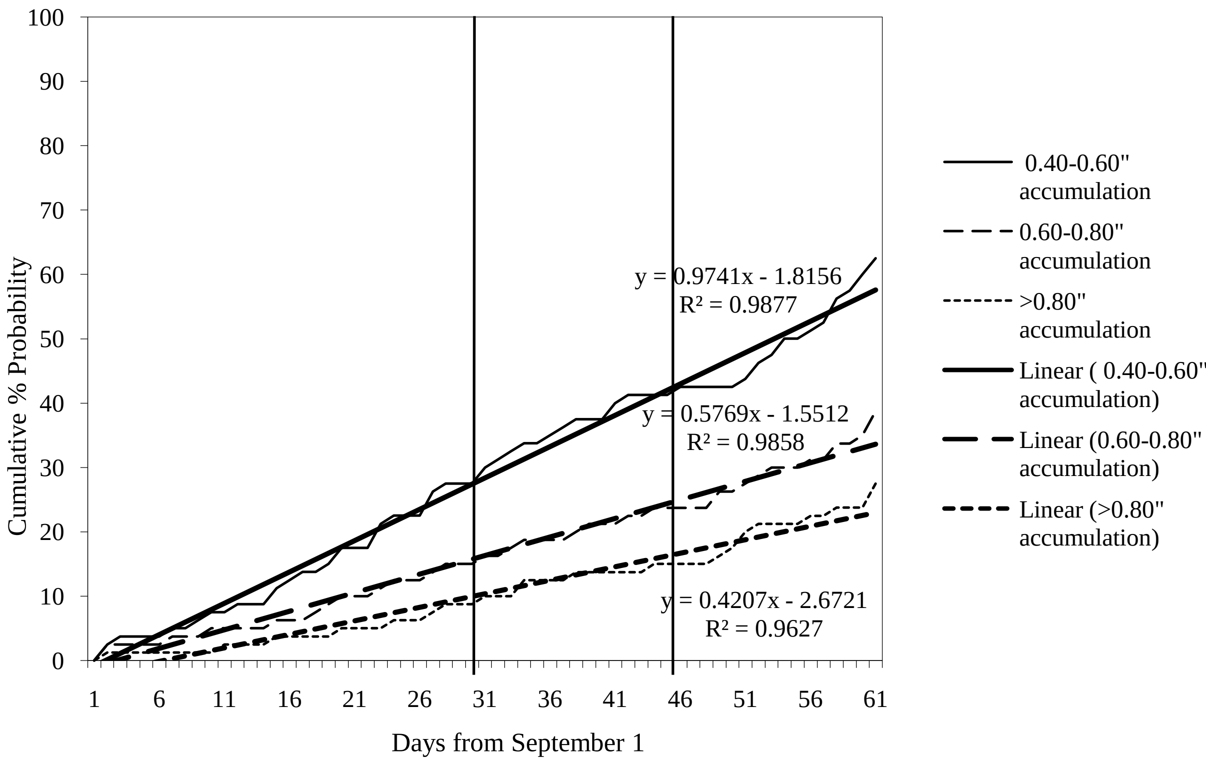

Figure 1. Likelihood of receiving specific amounts of rainfall in 3 days at Moro, Oregon.

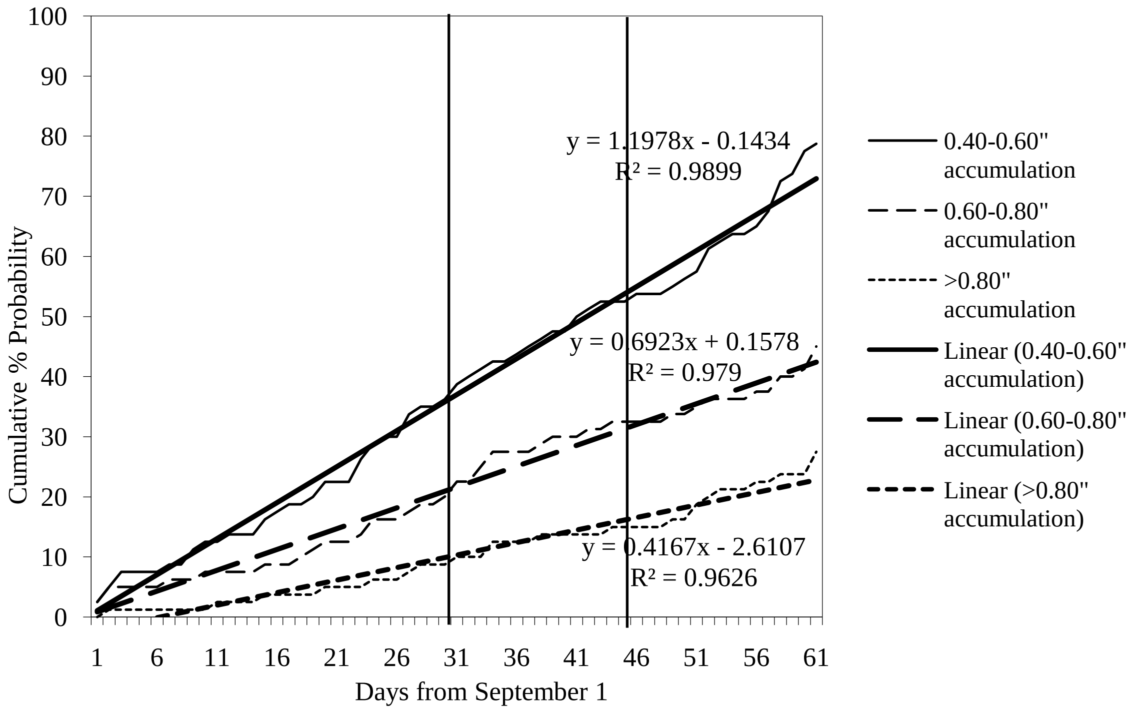

Figure 2. Likelihood of receiving specific amounts of rainfall in 5 days at Moro, Oregon.

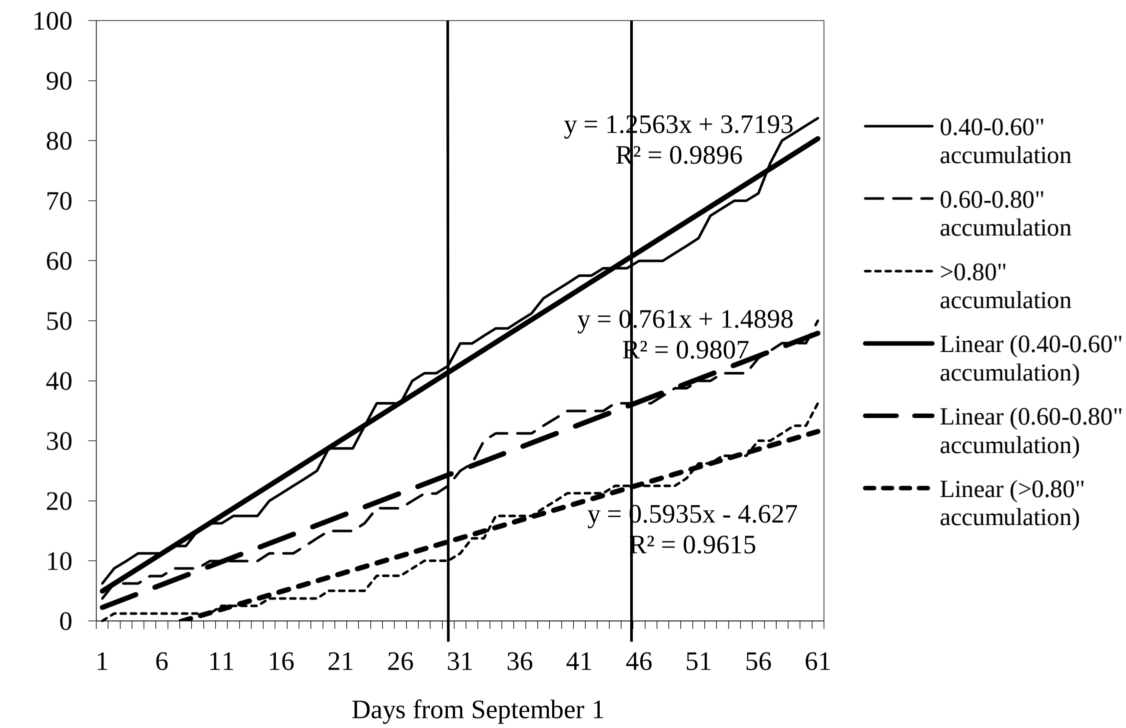

Figure 3. Likelihood of receiving specific amounts of rainfall in 7 days at Moro, Oregon.

Conclusion

This information can be used to help inform decision making about potential seeding dates. This information is helpful to determine the likelihood of successful seeding after chemical fallow where the moisture line is usually too deep to successfully seed winter wheat using a deep furrow drill. In these situations, seeding must be delayed until there has been sufficient rain to wet the surface soil to the moisture line. Another situation involves crops that must be seeded early so that they achieve a specific growth stage to minimize winter injury. In both situations, the information in the figures can be used to calculate the likelihood of combinations of rainfall amount and time during which the rainfall occurs.

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Dryland Adaptation and Nitrogen Response of Waxy Spring Wheat Lines in Northeastern Oregon

Steve Petrie

Abstract

Wheat starch is composed of amylose and amylopectin; amylose is made up of straight chains of glucose units while amylopectin is composed of branched chains of glucose units. Wheat with a high percentage of amylopectin is referred to as “waxy” wheat; this character may confer unique textures and other properties to food products made using waxy wheat. This waxy character has recently been incorporated into soft white spring germplasm. However, advanced lines and ‘WaxyPen’, a recently-released variety, have not been evaluated in the low-rainfall region of northeastern Oregon. The objectives of this field research were to determine the yield potential, test weight, and grain protein of ‘WaxyPen’ and two selected advanced lines and to determine the nitrogen (N) response of ‘WaxyPen’. Variety trials were conducted in 2006 and 2007 at the Sherman (11 inches precipitation) and Pendleton (17 inches precipitation) stations of the Columbia Basin Agricultural Research Center. All trials were seeded at 22 seeds/ft^2 using a Hege small plot grain drill; individual plots were 5 ft by 20 ft. A N response trial was conducted at Pendleton in 2006 and 2007 using ‘WaxyPen’ and ‘Alpowa’, a widely grown soft white variety. Preplant N was applied at rates from 0 to 150 lbs N/acre in 30 lb increments. Treatments were arranged in a randomized complete block design with four replications. Standard production practices were used in all trials. The trials were harvested using a Wintersteiger small plot combine, the grain was cleaned and weighed to determine yield, and a subsample was used to determine test weight and protein. Differences in yield, test weight, and grain protein were observed but no consistent differences between entries were noted. N fertilization increased yield and protein of both varieties. ‘WaxyPen’ produced slightly less grain than ‘Alpowa’ but with higher grain protein in 2006 and similar grain yields with lower grain protein in 2007.

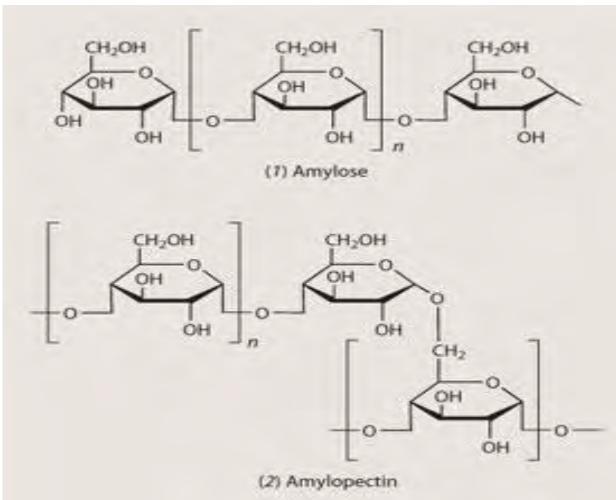
Key words**:** nitrogen fertilizer management, spring wheat, waxy wheat

Introduction

Economic pressures continue to impact growers as commodity prices fall in the wake of the weakening world economy. Although some weakening in input prices has lessened the economic pressure on growers, the future is likely to hold more financial challenges for wheat producers. We must develop ways for growers to increase profitability in the face of a depressed world market for wheat. The development of wheat with novel genetic traits that can reduce production costs and increase market segmentation add value to wheat and offer growers the opportunity to increase profitability. Examples include Clearfield® varieties of winter wheat that are resistant to Beyond® herbicide, and hard white wheat currently under development at Oregon State University (OSU).

Another option is the production of wheat with unique starch characteristics, such as waxy wheat, which has starch that imparts a waxy, glossy appearance, hence the name. Wheat starch is composed of two types of glucose polymers. Normal soft white spring wheat is composed of amylose, which consists of straight chain polymers. In waxy wheat, the starch is composed of amylopectin that has branched polymers. The structure of the two different starches is shown in Figure 1.

Figure 1. Amylose and amylopectin



Soft white wheat from the Pacific Northwest (PNW) is used for cookies, cakes, udon noodles, and flat breads. The branching nature of the amylopectin permits the wheat to absorb and retain more water when dough is frozen and subsequently thawed, for example in frozen bread dough products. This property permits products made from waxy wheat to stay fresh longer than the same product made from non-waxy wheat. Finally, baked products made from waxy wheat remain crispy longer. Thus, waxy wheat would have a different suite of end uses than the traditional soft white wheat.

Spring wheat is less productive than winter wheat in the dryland PNW and growers are reluctant to grow spring wheat because of the yield loss and resulting reduction of economic return. However, many growers are forced to produce spring wheat once every 3 to 5 crops of winter wheat to help control weeds such as downy brome (*Bromus tectorum*) and jointed goat grass (*Aegilops cylindrical*). The opportunity to produce a higher value crop may reduce the economic penalty associated with the reduced yield of spring wheat.

Unfortunately, there is little agronomic information available on these unique wheat lines. These lines have not been evaluated to determine if they are adapted to production under dryland conditions in north central and northeastern Oregon. It is important for us to determine if these lines can be successfully grown in the dryland region and to assess the effect of nitrogen (N) management on the yield and quality of waxy wheat. The objectives of this research were to compare the yield and quality and the N response characteristics of waxy and conventional spring wheat varieties at Pendleton and Moro, Oregon.

Materials and Methods

Field trials were conducted at the Pendleton and Moro Stations of the Columbia Basin Agricultural Research Center in 2006 and 2007. The trials were seeded in early March both years at both sites at a seeding rate of 25 seeds/ft^2 using a small plot drill. The previous crop was fallow both years at Moro, and at Pendleton, fallow in 2006 and winter wheat in 2007. All agronomic practices were typical for the respective production areas. The soil contained 62 lb of N in the top 4 ft of the profile in 2006 and 65 lbs of N in 2007. Nitrogen fertilizer was applied at a rate of 0 to 150 lbs of N/acre in 30 lb increments in the N rate study. Rainfall in the 2005, 2006, and 2007 crop water years was 7.9, 16.9, and 11.1 inches, respectively, at the Sherman Station and 12.2, 18.9, and 15.3 inches, respectively, at Pendleton. Plant height was measured at maturity and the trials were harvested with a Wintersteiger small plot combine. The grain was cleaned and weighed to determine grain yield, test weight was measured, and protein concentration was determined using NIR spectroscopy. Nitrogen uptake was calculated by multiplying the N concentration in the grain by the yield.

Results and Discussion

Variety adaptation

2006

Plants averaged almost 4 inches taller at Pendleton than at Moro (Table 1) in 2006. The waxy variety 'IDO629' was the tallest variety at both sites while 'IDO630' was the shortest variety at both sites. 'IDO630' was the most productive variety at both Pendleton and Moro, although the yields were not statistically significant different at Pendleton. There were significant differences in test weight values at both sites but there were no consistent differences in test weight between the conventional and waxy wheat varieties.

Table 1. Plant height, yield, and test weight of five varieties of spring wheat varieties at Pendleton and Moro, Oregon, 2006.

Variety	Pendleton			Moro		
	Plant ht.	Yield	Test wt.	Plant ht.	Yield	Test wt.
	--- in ---	bu/acre	lb/bu	--- in ---	bu/acre	lb/bu
Alpowa	30	64.1	58.9	25	52.1	59.9
Alturas	29	66.0	61.6	25	50.3	59.8
Waxy Pen	26	64.2	60.2	24	52.1	60.1
IDO 629	32	64.8	59.1	26	48.8	58.4
IDO 630	28	68.2	60.7	24	54.2	60.5
$LSD_{(0.05)}$	1.7	ns	0.9	1.7	5.3	0.9

2007

Grain yields were reduced in 2007 compared to 2006 at Pendleton because there was less precipitation (18.9 vs 15.3 inches) and the trial was conducted after a winter wheat crop in 2007 whereas it was after fallow in 2006. Grain yield at Moro was greater than at Pendleton because the trial at Moro was planted after fallow. 'IDO630' produced significantly greater yield and higher test weight than the other varieties at Pendleton. 'IDO630' had the greatest yield at Moro as well, although the yield was not significantly greater than the yield of some other varieties. 'WaxyPen' produced the least yield at both Pendleton and Moro. Test weight values were greater at Moro than at Pendleton; this is consistent with the greater moisture availability at Moro after fallow than at Pendleton. Grain protein was greater at Pendleton than at Moro but there were no consistent differences between conventional and waxy varieties.

Yields of the conventional and waxy spring wheat varieties were similar in both years and in both high and low yielding cropping conditions. Thus, there does not appear to be a yield penalty associated with the production of waxy spring wheat varieties.

Table 2. Grain yield, test weight, and grain protein of five varieties of spring wheat varieties at Pendleton and Moro, Oregon, 2007.

Variety	Pendleton			Moro		
	Yield bu/acre	Test wt. lb/bu	Protein --- % ---	Yield bu/acre	Test wt. lb/bu	Protein --- % ---
Alpowa	33.3	57.9	11.9	56.0	61.0	9.1
Alturas	35.8	58.3	11.8	53.8	60.0	8.9
Waxy Pen	31.4	57.0	12.2	45.2	60.8	9.5
IDO 629	33.0	58.3	11.5	52.1	60.5	8.6
IDO 630	41.1	59.1	12.0	57.6	61.5	8.3
$LSD_{(0.05)}$	5.0	0.8	0.4	8.6	0.4	0.7

Nitrogen Response

2006

The N response trials were conducted only at Pendleton; 'WaxyPen' and 'Alpowa' were seeded because both were commercially available as seed. Increasing the rate of N fertilizer applied increased grain yields (Fig. 1); the highest yield of 'Alpowa' occurred when 90 lbs N/acre was applied. Yields of 'WaxyPen' increased as the N rate was increased from 0 to 60 lbs N/acre with a slight yield increase at the highest rate of N. 'Alpowa' produced slightly greater yields than did 'WaxPen' at the same N rates. Grain protein decreased at the first increment of N fertilization due to dilution of the grain N by an increase in biomass. After the initial decline in grain protein, additional N fertilizer increased grain protein with 'WaxyPen' exhibiting greater grain protein concentration at each N fertilizer rate. The grain protein concentration of 'WaxyPen' was 14 percent or greater at N rates of 90 lbs N/acre or greater while the highest protein concentration of 'Alpowa' was only 13.8 percent. The maximum yield of 'Alpowa' was achieved at 90 lbs N/acre, which resulted in 12.9 percent grain protein.

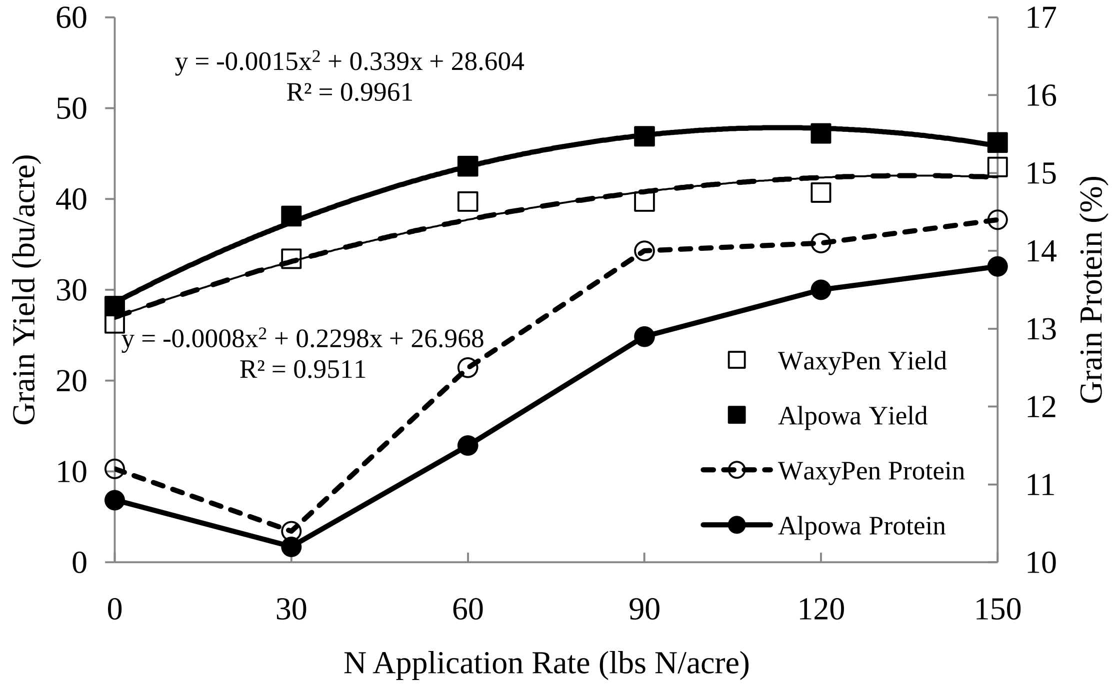


Figure 1. Nitrogen fertilization inceased grain yield and protein of conventional and waxy spring wheat at Pendleton, Oregon, 2006.

2007

'Alpowa' and 'WaxyPen' were less responsive to N application in 2007 than in 2006, presumably because the drier conditions limited yield. 'WaxyPen' and 'Alpowa' produced similar yields at all N rates except the highest; the yield of 'Alpowa' increased when the N rate increased from 120 to 150 lb N/acre but the yield of 'WaxyPen' decreased at the highest N rate (Fig. 2). Grain protein concentration was lower in 2007 than in 2006 at comparable N application rates, with the exception of the protein decrease due to the dilution effect noted above. The grain protein concentration of 'WaxyPen' exhibited the initial dilution effect-protein decline at the first rate of N but 'Alpowa' did not. 'WaxyPen' had greater protein concentration than 'Alpowa'at all N rates except at 30 lbs N/acre.

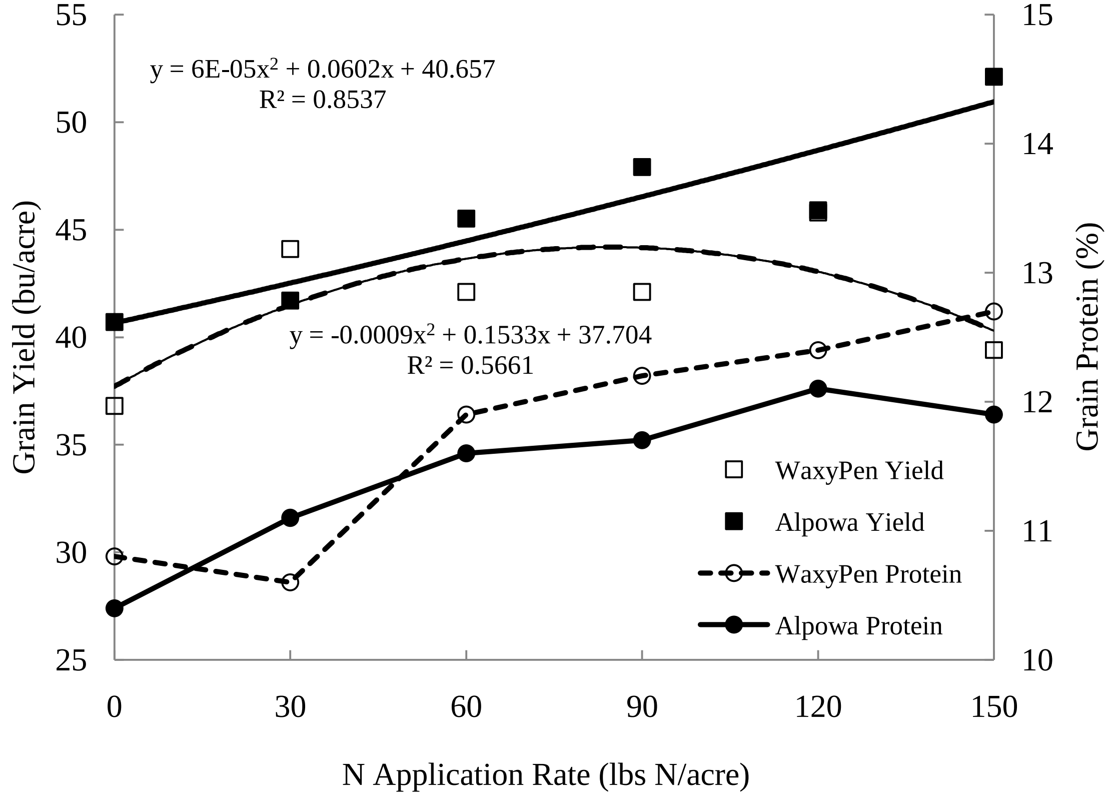


Figure 2. Nitrogen fertilization inceased grain yield and protein of conventional and waxy spring wheat at Pendleton, Oregon, 2007.

Grain N Uptake

Increasing the rate of N fertilization resulted in greater grain N uptake (Fig. 3) except when the highest N rate was applied to 'Alpowa'. The greatest grain N uptake approached 70 lbs N/acre when 90 lbs N/acre or greater was applied. The total plant N uptake would include the N in the straw, chaff, etc.; the total plant N uptake was not measured in this study.

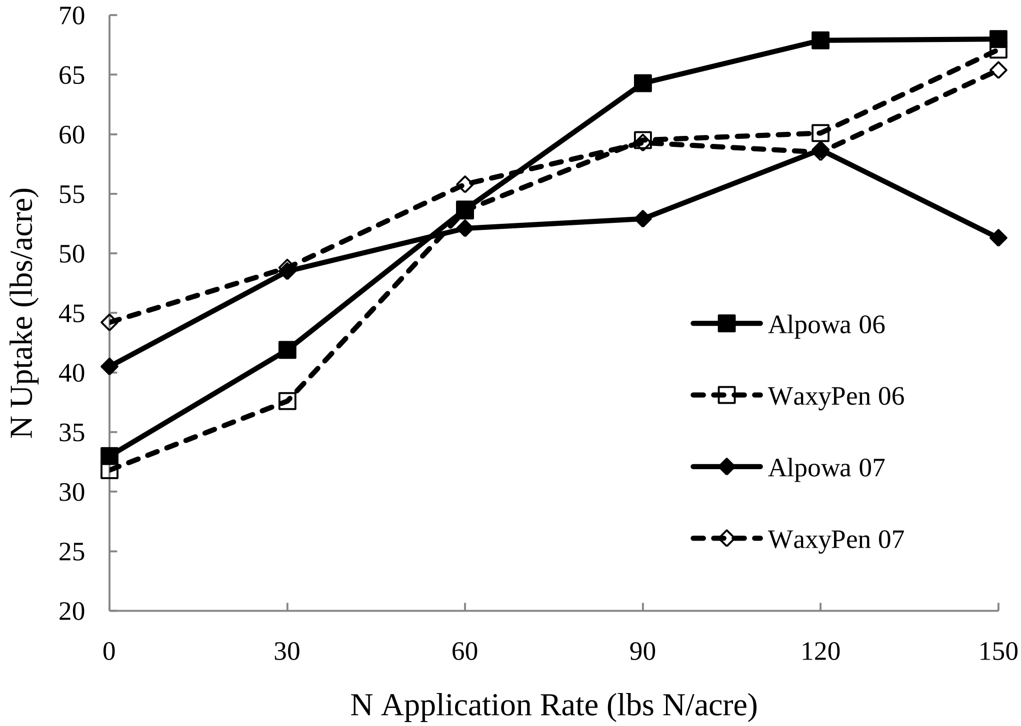


Figure 3. Nitrogen fertilization increased grain N uptake at Pendleton, Oregon, 2006 and 2007.

Grain N Uptake Efficiency

Nitrogen uptake efficiency can be calculated in several ways. The amount of N taken up in the grain that was derived from the applied N fertilizer cannot be determined in this study, but we can estimate the increased N uptake that occurred as the rate of N application increased. This value can be calculated by subtracting the N uptake in the grain when no N was applied from the grain N uptake at each N application rate and dividing by the N application rate. The values are then converted to a percentage. Nitrogen uptake efficiency increased as the N rate increased from 30 to 60 lbs N/acre in 2006 and then fell as more N was applied (Fig. 4). The grain N uptake was as high as 35 percent of the applied N when 60 lbs of N was applied and the grain N uptake was about 25 percent of the applied N when 150 lbs N/acre was applied. 'WaxyPen' and 'Alpowa' exhibited similar N uptake curves.

In 2007, 'WaxyPen' exhibited the same general response as in 2006 but the grain N uptake increased only about 20 percent of the increased N application rate. Grain N uptake was increased by about 25 percent at the first N increment, but the values fell as the N application rate increased and the grain N uptake increased by less than 10 percent at the highest N application rate.

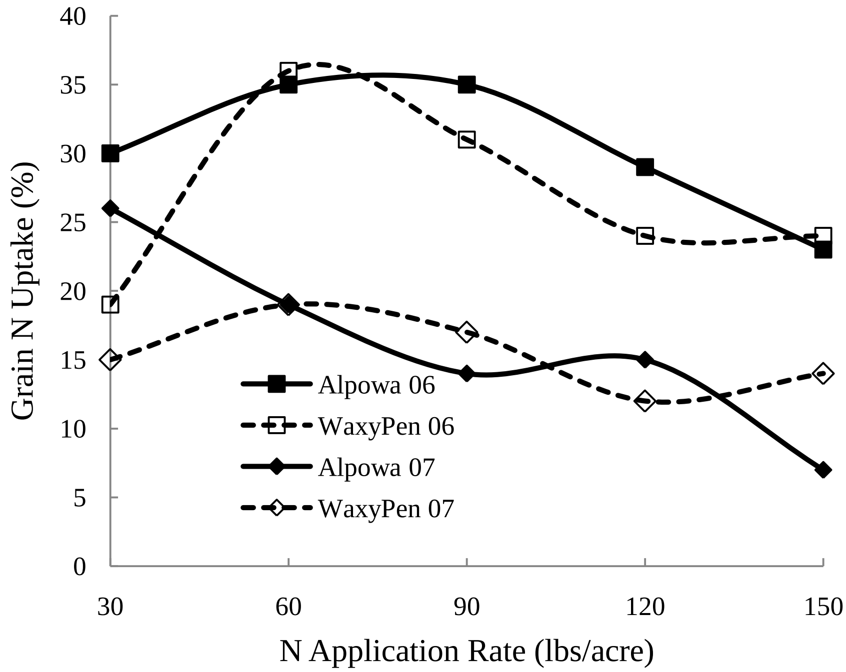


Figure 4. Grain nitrogen uptake at different rates of applied N at Pendleton, Oregon, 2006 and 2007.

Summary

The results from 2years of field trials at Pendleton and Moro show that waxy type spring wheat varieties can be successfully grown without any yield loss compared to conventional soft white spring wheat varieties. The response to N fertilizer was similar between 'WaxyPen', the waxy wheat variety we studied, and 'Alpowa' spring wheat; growers should be able to use the OSU fertilizer guides for spring wheat for both conventional and waxy varieties.

Acknowledgements

I wish to express my appreciation to the Oregon Wheat Commission and the Oregon Agricultural Experiment Station for their support of this research.

Using the Undercutter Sweep in a Reduced Tillage Summer Fallow System

Steven Petrie

Abstract

The winter wheat-summer fallow system dominates the dryland cropping landscape in eastern Oregon because 2 years of moisture are used to produce one crop, which increases wheat yield and reduces economic risk. Tillage, typically rodweeding, is used to set a moisture line that permits timely seeding in the fall, and to control weeds during the summer fallow phase. Unfortunately, this tillage often leaves the soil surface exposed and vulnerable to wind and water erosion. The use of broad spectrum herbicides to control weeds without tillage, called chemical fallow, leaves the soil surface undisturbed and minimizes the potential for erosion. However, seed-zone moisture is often lost due to evaporation and seeding must be delayed until adequate rain has fallen in autumn to permit seeding. The undercutter sweep, a relatively new tool in the Pacific Northwest, causes minimal soil surface disturbance but sets a moisture line similar to a rodweeder. The undercutter sweep was evaluated in 2 years of trials at the Sherman Station of the Columbia Basin Agricultural Research Center. Using an undercutter sweep, combined with glyphosate for weed control, was as effective as using an undercutter sweep followed by rodweeding at maintaining adequate moisture in the seed zone in early September. All treatments had sufficient residue to reduce erosion. Rodweeding increased soil cloddiness in the surface and subsurface samples in 2006 but not 2007. Grain yields, protein, test weight, and kernel weight were similar regardless of tillage treatment. The results of this research, coupled with related work in the region, led the Natural Resources Conservation Service to develop a cost share program to encourage growers to purchase undercutter sweeps.

Key words: Chemical fallow, soil moisture, summer fallow, undercutter sweep

Introduction

The winter wheat-summer fallow system is widely practiced in the low and intermediate rainfall zones of eastern Oregon. Crop yields are larger and more consistent after summer fallow because the precipitation in 2 years is used to produce one crop of winter wheat. Tillage-based summer fallow is widely used but it may leave the soil surface exposed and vulnerable to water and wind erosion. Rodweeding controls weeds that germinate during the late spring and summer and is thought to disrupt the capillary channels from the subsoil to soil surface thereby reducing soil water loss during the summer. Winter wheat can successfully be sown in September because the seeds are placed into moisture using standard deep-furrow grain drills.

Chemical fallow, which relies on herbicides to control weeds during the summer months, is gaining popularity because there is often more crop residue left on the surface to control erosion. However, chemical fallow does not create a "dust mulch" so evaporation losses occur throughout the summer and the soil is often too dry to seed at the appropriate time in the early fall, especially in the low rainfall areas (Schillinger and Bolton 1992). Delayed seeding often results in reduced yields (Flowers et at. 2008), reduced profitability, less straw production, and less sustainability. Growers want to use a system that protects the soil resource while also permitting timely seeding in the fall.

The Haybuster™ undercutter sweep is a primary spring tillage implement that has overlapping 32-inch-wide adjustable pitch sweep blades so the "angle of attack" of the blade can be adjusted for different field conditions (Fig. 1). The blade pitch is adjusted so it stays at the desired depth and does not ride up out of the soil. Liquid fertilizer can be applied behind the back of the blade. The undercutter sweep breaks the capillary connection between the subsurface and surface soil, thereby reducing evaporative water loss while still retaining most of the crop residue on the soil surface to reduce erosion. The undercutter sweep can also be used to control Russian thistle after harvest; a properly adjusted undercutter sweep causes little surface soil disturbance (Fig. 2) and leaves the residue on the surface.

Figure 1. A small plot undercutter sweep with fertilizer application option.

Figure 2. Commercial undercutter sweep being used after harvest to control Russian thistle showing minimal residue disturbance.

There is little local experience with the undercutter sweep so we purchased a used sweep from the Great Plains region with funds from the Sherman Station Endowment Fund. We conducted field trials with the undercutter sweep in the 2006-2007 and 2007-2008 crop years. The objectives of this research were to evaluate the use of the undercutter sweep and the frequency of rodweeding operations on (1) seed-zone moisture retention, (2) surface residue retention, (3) surface cloddiness, (4) subsurface cloddiness just before planting winter wheat in late August, and (5) grain yield and quality.

Materials and Methods

Trials were established at the Sherman Station of the Columbia Basin Agricultural Research Center in the spring of 2006 and 2007. Primary spring tillage was conducted at a depth of 5 inches with a Haybuster undercutter V-shaped sweep. All subsequent rodweeding operations were conducted at a 4-inch depth with a Calkins center-drive rodweeder. The following treatments were used:

1. No rodweeding; weeds were controlled with glyphosate applied as needed during the summer.
2. Rodweed only when required to control weeds (this was done three times in 2006 and twice in 2007).
3. Rodweed immediately after primary spring tillage, but thereafter only as required to control weeds (this was done a total of three times each year).
4. Rodweed immediately after primary spring tillage and then at 1-month intervals until late July-early August (this was done a total of five times each year).

The treatments were arranged in a randomized block design with four replications. Soil volumetric moisture in the soil profile was measured prior to primary tillage and volumetric water content in the seed zone just prior to seeding was determined in each plot in 0.75-inch increments to a depth of 12 inches in 2006 and in 1-inch increments to 12 inches in 2007. I measured surface residue by clipping and collecting the residue within a 3 ft diameter ring placed randomly in each plot. Surface and subsurface cloddiness were measured at the end of the fallow phase just prior to seeding. Surface soil cloddiness was measured by collecting, counting, and weighing all surface clods within a 3 ft diameter ring. All clods greater than 2 inches were collected and divided into 1-inch-increment classes. Subsurface cloddiness was determined by gently sieving 0.35 ft^3 of soil from the top 4 inches through stacked sieves with screens with 0.5, 1.0, and 2.0 inch openings. The area was seeded in mid-September, 2006 and late October, 2007 because there was insufficient rainfall to seed earlier. Grain was harvested with a plot combine and yield estimated. We also measured grain protein, test weight, and 1,000-kernel weight in 2007.

Results and Discussion

Soil moisture

Seed must be placed into soil with at least 11 percent moisture on a volumetric basis for successful germination and emergence (Schillinger and Young 2004) although germination is more uniform at greater moisture content. All four treatments resulted in 11 percent or greater volumetric soil moisture at 5 inches, the normal seeding depth using a deep furrow drill. The undercutter sweep followed by glyphosate for weed control was as effective as rodweeding at maintaining seed-zone soil moisture of 11 percent or greater in early September, 2006 (Fig. 3) and 2007 (Fig. 4). This indicates that the use of the undercutter sweep followed by glyphosate applications was as effective as the practice of undercutting followed to 1 to 5 rodweeding at maintaining seed-zone moisture. There was more soil moisture in 2006 than in 2007 because there was 16.9 inches of precipitation in 2005-2006 compared to only 11.1 inches in 2006-2007. There was only 8.7 inches of precipitation in the 2007-2008 growing season.

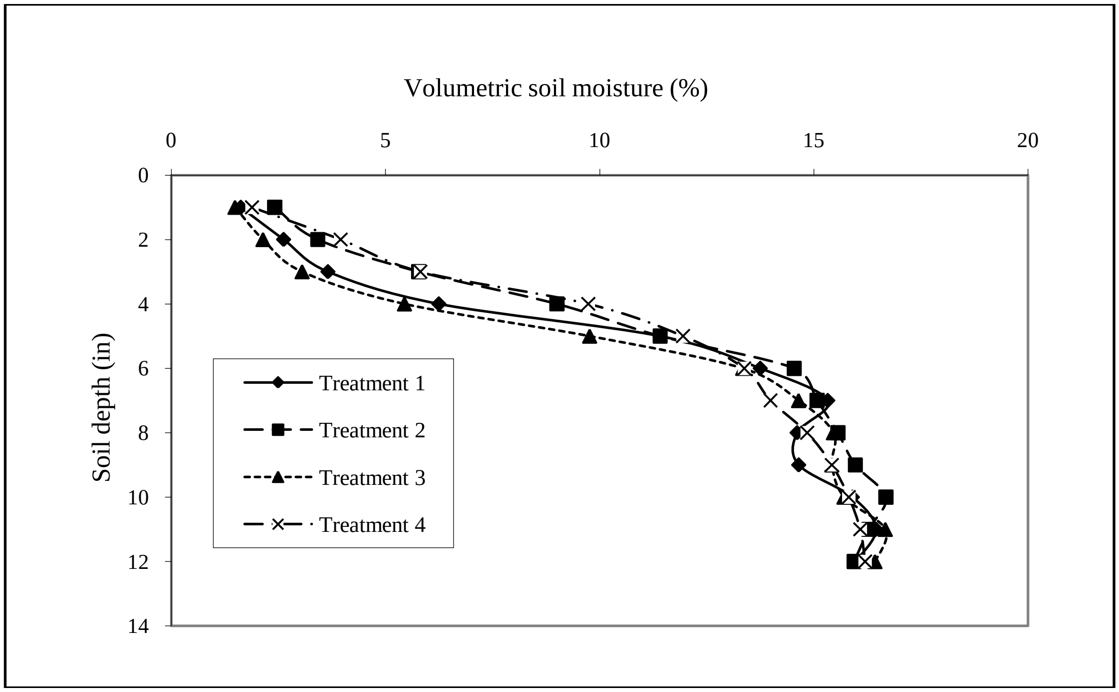


Figure 3. Effect of various tillage treatments on seed-zone moisture, Moro, Oregon, 2006. Treatments: 1. no rodweeding; weeds controlled with glyphosate as needed during summer;
2. rodweed only when required to control weeds; 3. rodweed immediately after primary spring tillage, then only as needed to control weeds; 4. rodweed immediately after primary spring tillage and then monthly until late July-early August.

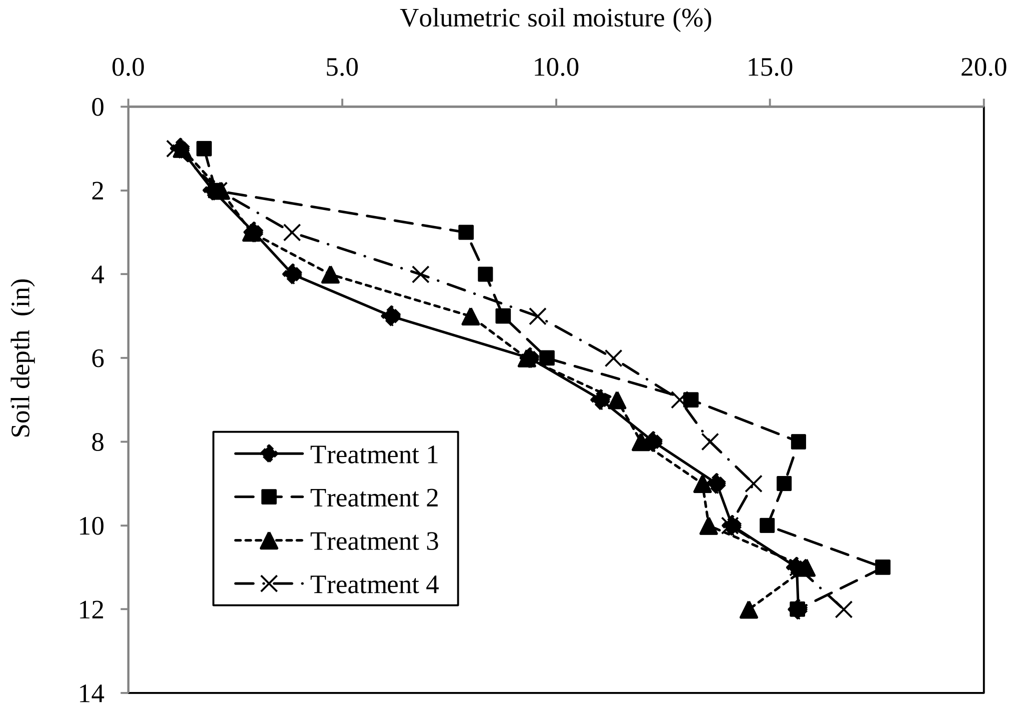


Figure 4. Effect of various tillage treatments on seed-zone moisture, Moro, Oregon, 2007. Treatments: 1. no rodweeding; weeds controlled with glyphosate as needed during summer; 2. rodweed only when required to control weeds; 3. rodweed immediately after primary spring tillage, then only as needed to control weeds; 4. rodweed immediately after primary spring tillage and then monthly until late July-early August.

Surface residue

The amount of surface residue in 2006 was similar whether the initial undercutter sweep was followed by rodweeding or not (Table 1). All treatments maintained substantial amounts of surface residue that would markedly reduce the potential for soil erosion from wind and water.

In contrast, there was greater surface residue in 2007 when there was no rodweeding after the initial undercutter sweep; the difference was significant at $P<0.10$. There was an average of 3,560 lb of residue in the plots that were rodweeded compared to 5,110 lb of residue in the plot that was not rodweeded.

Table 1. Effect of tillage on surface residue, Moro, Oregon, 2006 and 2007.

Treatment	2006	2007
	------------- Lbs/acre	--------------
1	3,925	5,105
2	3,435	3,685
3	4,295	3,485
4	3,980	3,510
LSD $_{(0.05)}$	ns	ns

Surface clods

In 2006, the undercutter sweep followed by herbicides to control weeds resulted in far fewer surface soil clods than when the rodweeder was used after the initial sweeping (Table 2). The initial undercutter sweep operation resulted in little surface soil disturbance but was performed when the soil was excessively wet and subsequent rodweeding moved the clods to the surface. These clods interfered with the seeding operation and resulted in uneven emergence of the seedlings. These differences in cloddiness and early seedling emergence did not affect grain yields or quality. In contrast, all treatments resulted in roughly equal amounts of clods in 2007.

Table 2. Effect of tillage treatments on surface soil clods at Moro, Oregon, 2006 and 2007.

Treatment	Clod diameter 2006					Clod diameter 2007				
	2-3 in	3-4 in	4-5 in	5-6 in	>6 in	2-3 in	3-4 in	4-5 in	5-6 in	>6 in
	---------- no./yd^2 ----------									
1	2.2	0.7	0.7	0.2	0	11.3	9.0	3.1	1.0	1.9
2	20.5	14.2	4.2	1.2	0.5	17.5	9.8	4.2	1.9	1.0
3	22.0	10.7	4.7	1.5	1.0	14.8	9.0	3.3	1.9	2.1
4	19.2	11.7	3.2	1.0	0.2	17.3	5.8	2.3	0.6	0
LSD $_{(0.05)}$	9.2	4.6	3.5	ns	ns	ns	ns	ns	ns	1.2

Treatments: 1. no rodweeding; weeds controlled with glyphosate as needed during summer; 2. rodweed only when required to control weeds; 3. rodweed immediately after primary spring tillage, then only as needed to control weeds; 4. rodweed immediately after primary spring tillage and then monthly until late July-early August.

Subsurface cloddiness

In both years, there were markedly more large subsurface clods (>2 inches) when the undercutter sweep was used without additional tillage (Table 3). In 2006, treatment 2 had significantly more small (0.5-1 inch) and intermediate (1-2 inches) clods than treatment 4. In 2007, treatment 1 had more clods of all sizes than other treatments and the differences were often significant.

Table 3. Effect of tillage treatment on the weight of subsurface clods at Moro, OR, 2006 and 2007.

Treatment	2006			2007		
	½ - 1 in	1-2 in	>2 in	½ - 1 in	1-2 in	>2 in
	---------- Grams per square meter ----------					
1	830	720	2,335	1,600	1,610	1010
2	1,220	925	310	940	950	350
3	960	595	380	1,190	850	540
4	760	460	20	975	525	130
LSD $_{(0.05)}$	445	280	1,555	585	610	695

Grain yield, test weight, protein, and kernel weight

The grain yield, test weight, protein, and kernel weight were unaffected by the tillage treatment in either year (Table 4), demonstrating that the consistent surface soil moisture led to similar crop growth. Yields were reduced in 2008 because there was only 8.7 inches of precipitation the crop water year.

Table 4. Effect of tillage treatments on average grain yield, test weight, protein, and kernel weight of winter wheat at Moro, Oregon, 2007 and 2008.

Treatment	2007				2008
	Grain yield bu/ac	Test wt. lbs/bu	Protein --- % ---	Kernel wt gm/1,000	Grain yield bu/ac
1	65.5	60.0	10.6	41.1	31.1
2	58.8	59.0	11.0	40.7	31.9
3	66.5	60.0	11.1	41.1	31.1
4	64.7	59.7	10.5	40.4	31.9
$LSD_{(0.05)}$	ns	ns	ns	ns	ns

Summary and Conclusions

A 2-year study was conducted at the Sherman Station to evaluate the use of the undercutter sweep plus glyphosate applications and the undercutter sweep with several rodweeding frequencies. The results of this study suggest that the use of the undercutter sweep alone sets a moisture line comparable to the undercutter with 1 to 5 rodweeding operations, while leaving more crop residue on the soil surface. Winter wheat yields and crop quality were comparable in all treatments.

Acknowledgements

I wish to express my appreciation to the Oregon Agricultural Research Foundation and the Oregon Experiment Station for providing partial support for this research. I also wish to thank the Sherman Station Endowment Fund for purchasing the undercutter sweep.

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Variability of the Screening Test for Identifying Fusarium Crown Rot Tolerance in Wheat

Richard Smiley, Hui Yan, Jason Sheedy, Alison Thompson, Sandra Easley,
Ruth Whittaker, Jennifer Gourlie, Karl Rhinhart, and Erling Jacobsen

Abstract

Fusarium crown rot (dryland foot rot) reduces the yield of wheat throughout the Pacific Northwest. Disease management options are quite limited and would be best achieved through development of varieties with disease tolerance or disease resistance. Scoring of crown rot symptoms in traditional field nurseries has not been particularly useful for identifying varieties with adult-plant tolerance. Inoculated field experiments were therefore used to determine if differences in varietal responses to the pathogen could be detected. Wheat yields in inoculated and noninoculated plots were compared for groups of spring wheat and winter wheat. Significant differences in crown rot responses were identified among spring wheat entries. We found that varietal differences for spring wheat could be accurately described using 24 comparisons, which is equivalent to 6 experiments in which treatments were replicated 4 times. However, this screening method was found to be impractical for winter wheat due to relatively small differences among varieties and strong effects of the year and location on the phenotypic reaction. About 95 yield comparisons would be required to accurately define the crown rot phenotypic reaction for winter wheat varieties. We concluded that future research with winter wheat should be focused on seedling resistance in greenhouse tests rather than adult-plant tolerance in field tests.

***Keywords**:* Fusarium crown rot, spring wheat, winter wheat

Introduction

Fusarium crown rot causes a rotting of the crown and lower stem tissues of wheat tillers and, when severe, is often first noticed when whiteheads appear in the crop canopy (Bockus et al. 2009). This disease causes chronic and occasionally severe damage to wheat throughout the world (Smiley et al. 2009). Several *Fusarium* species are capable of causing crown rot and the most important species in an individual field varies from region to region and from year to year. *Fusarium pseudograminearum* is more widespread and more damaging than *F. culmorum* in most areas of Oregon, but very important reversals of that trend occur in several locations in each of the Pacific Northwest (PNW) states (Smiley and Patterson 1996, Paulitz et al. 2002, Strausbaugh et al. 2004). Winter wheat yields have been reduced as much as 35 percent by *F. pseudograminearum* in commercial fields and as much as 61 percent when soils have been inoculated with the pathogen (Smiley et al. 2005). Damage from crown rot is more widespread and damaging than generally recognized because above-ground symptoms are not always apparent under conditions of moderate infection and yield constraint.

Conservation tillage practices and greater cropping frequency are contributing to an increasing incidence and severity of crown rot worldwide (Summerell et al. 1989; Smiley et al. 1996, 2009; Wildermuth et al. 1997) and cultural management strategies are only partially effective for controlling the damage in the PNW (Paulitz et al. 2002). Commercially acceptable levels of genetic resistance are not yet available but partial seedling resistance and adult-plant tolerance can reduce the amount of damage to stem tissues and increase the yield of wheat (Burgess et al., 2001). This has been studied in greatest detail in Australia. Winter wheat cultivars in the PNW have been screened repeatedly for tolerance in naturally infested soils during the past four decades. Symptoms of crown rot severity (degree of browning of the basal stem) or incidence (percent stems with brown discoloration or whiteheads in crop canopy) were used for these evaluations. Results have been highly variable over years and test sites and have not yet successfully identified a variety or line that is clearly and consistently tolerant to crown rot. We have also learned that the complex relationship between disease symptoms and grain yield have made it almost impossible to predict yield loss based on visible symptoms (Smiley et al. 2005).

An inoculation method to directly measure the relative impact of crown rot on grain yield has emerged as the most efficient procedure to evaluate the level of field tolerance expressed by individual wheat varieties and breeding lines. This screening procedure (Smiley et al. 2005) is accomplished by comparing grain yields between adjacent plots of native soil, one untreated and the second treated with inoculum of the pathogen at the time of planting. The inoculation procedure creates a high level of uniformity of the pathogen and of the disease potential within inoculated areas of the screening nursery. Screening nurseries are typically performed as strip plots with individual wheat cultivars occurring side-by-side in replicated inoculated and non-inoculated drill strips. Inoculation typically causes the grain yield to be lower in inoculated than non-inoculated plots. However, within each experiment there are likely to be at least some wheat entries that yield equally well in inoculated and non-inoculated soils, and other entries that have much lower yields in inoculated than in non-inoculated plots. When this occurs the entries with comparable yields are considered to be tolerant of the pathogen and entries with yields considerably lower in inoculated than in non-inoculated soil are considered to be intolerant. While a range of phenotypic responses commonly occurs within individual experiments, the relative rankings among entries often differ in identical experiments performed during subsequent years or at other locations.

Cereal researchers in Kansas (Bockus et al. 2007) recently described a method to calculate the number of experimental repetitions needed to achieve a given level of accuracy (margin of error) for assigning a phenotypic reaction of wheat cultivars to four foliar diseases. They determined that from 20 to 47 observations (5 to 12 successful experiments with 4 replicates per treatment) were required, depending on the specific disease, to define the resistance response at the 95 percent confidence interval. It seemed possible to apply this procedure to quantify the variable responses of cultivars to crown rot over years and across sites in the PNW.

We therefore evaluated the variability of crown rot tolerance reactions among spring and winter wheat cultivars and breeding lines, and estimated the number of experimental observations required to accurately define the phenotypic response for a typical wheat entry. Data for these analyses were 'mined' from the largest possible groups of common entries planted over the largest possible number of sites and years and using an identical inoculation procedure and strains (isolates) of the pathogen. This report is an abbreviated version of a manuscript (Smiley and Yan, 2009) being published in a technical journal.

Materials and Methods

Experiments were performed from 2000 to 2008 at the Columbia Basin Agricultural Research Center stations at Moro and Pendleton, where mean annual precipitation over the past 10 years has been 10.1 and 16.5 inches, respectively. The soil at both locations is a Walla Walla silt loam.

Seed was acquired from wheat breeders and pathologists in Oregon, Washington, Turkey, South Australia, and Queensland, and was treated with the fungicide benomyl (Benlate®) to reduce the potential for seedling damping-off. Seed was planted into conventionally tilled (chisel plow and rod weeder) summer fallow following winter wheat harvested either 6 months earlier for trials with spring wheat or 14 months earlier for trials with winter wheat. All plantings were made using a John Deere HZ split-packer deep-furrow drill with four hoe openers at 14-inch row spacing. Plots were either 6 by 20 ft or 6 by 30 ft, depending on the experiment. Winter wheat seed was planted from early to mid-September at depths of 2 to 4 inches, and spring wheat was planted from early to late March at depths of 1 to 2 inches.

Five isolates of *Fusarium pseudograminearum* were used to inoculate soil (Smiley et al. 2005). These isolates were collected from infected winter wheat crowns and were selected to represent a range of geographic origins and virulence ratings. The isolates were from farms in Sherman and Wasco counties in Oregon and Walla Walla County in Washington. Each isolate was increased individually on twice-autoclaved millet seeds. The *Fusarium*-colonized millet was air-dried and sieved to eliminate clumps and then blended in equal proportions to form a single composite inoculum before it was used to treat the soil.

Wheat entries were planted with and without inoculum. For inoculated plots, the colonized millet seed was banded 1 inch above the wheat seed so the wheat coleoptile would pass through the zone of inoculation prior to seedling emergence. Millet seed was metered from a Gandy fertilizer box mounted on the grain drill, and dispensed through an adjustable-depth tube mounted behind each of the four drill openers. Colonized millet seed was dispensed into soil at a rate of approximately 140 millet seeds/ft of row. Control treatments were planted without dispensing millet seed. The experimental design was a strip-plot with alternating inoculated and non-inoculated drill strips, with wheat entries occurring side-by-side as subplots in blocks replicated three to seven times depending on the experiment.

Grain was harvested from each plot using a Hege 140 small-plot combine. Yield data were converted to a percent yield difference for inoculated compared to non-inoculated plots to reduce bias caused by yield differences over years and locations. Data for percent yield reduction were analyzed by analysis of variance for individual experiments and for groups of experiments in which varieties or breeding lines that occurred in multiple tests were grouped over locations and years.

The number of observations (experiments by replicates) required to describe the crown rot tolerance reaction for individual wheat entries was determined using the margin-of-error analysis described by Bockus et al. (2007). Yield data for uniform groups of spring wheat or winter wheat entries were accumulated over multiple years and locations. For spring wheat the margin-of-error analysis was based on 20 yield comparisons for each of 17 wheat entries evaluated in 3 experi-ments with 2 inoculation levels (plus or minus inoculum) and 6 or 7 replicates per entry, for a total of 680 datum points. Four groups of winter wheat were evaluated. The first group included 28 yield comparisons for each of 16 wheat entries evaluated over 2 years at 2 locations with 2 inoculum levels and 7 replicates, for a total of 896 datum points. The second group included 48 observations for 7 wheat entries examined in 9 experiments with 3 to 7 replicates performed over a 9-year period at 2 locations, for a total of 672 datum points. The third group consisted of the removal of two experiments from the second group due to extraordinarily high yield reductions during tests at Moro and Pendleton during 2002 (37 observations, 560 datum points). The fourth winter wheat group consisted of the removal of the three experiments at Moro from the second group in order to examine variability across six years at Pendleton (27 observations, 420 datum points).

The number of observations required to define a crown rot phenotypic reaction within a given range of accuracy compared to the theoretically 'true' value was calculated using the formula $MOE = (t_{\alpha/2,n-1})(s/\sqrt{n})$, where *MOE* (margin of error) is the pre-specified deviation of the obtained ratings from the true rating, $t_{\alpha/2,n-1}$ is the $(1-\alpha/2)$ quantile of the *t* distribution with n - 1 degrees of freedom, *n* is the number of observations required, and *s* is the standard deviation of the obtained ratings. For example, we initially wanted to describe the phenotypic reactions at the 95 percent confidence interval, which represents a level of accuracy within ±5 percent of the 'true' value. We would therefore accept sufficient variability to accept as true an entry that had a theoretically true yield reduction of 10 percent but in our tests was observed to have ratings ranging from 5 to 15 percent. If that level of accuracy could not be achieved during our analysis we then determined the number of observations that would be required to attain that level of accuracy. These calculations assume that data for future experiments will have similar standard deviations and ranges of variability in the phenotypic response. The projected number of observations required was computed using equation 1 with the significance level α set at 0.05 to calculate the associated value of *n*. A plot summarizing the relationship between *MOE* and *n* for each of the five groups of wheat entries we examined was prepared by plotting the mean of *n* for all entries in each group at each specified *MOE*. Because high numbers of field observations were predicted for winter wheat we also calculated the number of observations required for a margin of error of ±10 percent.

Results

Yields of spring wheat

Yields of spring wheat entries were not reduced by Fusarium crown rot in a drought-stressed planting in which stand establishment was irregular and grain yields were very low at Moro during 2008. That experiment was therefore excluded from subsequent analyses. Analysis of the phenotypic reaction to crown rot in individual experiments revealed significant differences among spring wheat entries at Moro during 2007 and at Pendleton during 2008. Data for the three successful spring wheat experiments were grouped over locations and years and analyzed for effects of year, location, and wheat entry. The main effect for yield reduction was significant for location-year and wheat entry, and the interaction between these factors was also significant, indicating variable responses among wheat entries when tested at Moro compared to Pendleton. Overall, yield reductions from crown rot were greater during 2007 than 2008 (10 vs. 6 percent,

$LSD_{0.05}$ = 2 percent) and were greater at Moro than at Pendleton (15 vs. 6 percent, $LSD_{0.05}$ = 2 percent). Data for only 2007 were re-analyzed because successful experiments were completed at both locations during that year. The analysis confirmed that crown rot differed significantly among entries and locations and that the location by wheat entry interaction was significant. Likewise, when data for experiments at Pendleton during 2007 and 2008 were analyzed separately we found that significant differences did not occur for wheat entry or year, or for the year by entry interaction.

Yield reductions differed significantly among spring wheat entries at Moro during 2007 and at Pendleton during 2008. Yield reductions for individual varieties at Moro in 2007 ranged from 4 percent for 'Gala' to 24 percent for 'Puseas'. Yield reductions at Pendleton during 2008 ranged from 2 percent for 'Jefferson' to 12 percent for 'Eden'. When data for the three spring wheat experiments were grouped over years and locations, the yield reduction was found to be signify-cantly less for '2-49', 'Jefferson', 'Gala', 'Tara 2002', 'Sunco', and 'Macon' than for 302-5, 'Eden', 'Otis', and 'Puseus' (Table 1). The overall most tolerant spring wheat entry, '2-49', had the lowest standard error of the mean in only one of the three experiments. CT020615 had an intermediate average response to inoculation but had the highest standard error of the mean in two of three experiments. The least tolerant entry, 'Puseas', was intermediate in variability of yield responses among replicates within these three spring wheat experiments.

Yields of winter wheat

For the 16 winter wheat entries evaluated at Moro and Pendleton during 2007 and 2008, yield reductions differed significantly among the entries in experiments during 2007 at Pendleton and at Moro; yield reductions ranged from 2 percent for 'Stephens' to 12 percent for 'Altay 2000' at Pendleton and from a trace for CT980872 to 15 percent for CT000330 at Moro. When this grouping of experiments were analyzed together, the main effects were significant for year and location but not for wheat entry. The 3-way interaction for location by year by entry was not significant, and 2-way interactions were significant for year by location and for year by entry but not for location by entry, indicating different responses among cultivars when tested during different years. Yield reductions from crown rot were greater during 2008 than 2007 (12 vs. 5 percent, $LSD_{0.05}$ = 2 percent) and were greater at Moro than at Pendleton (11 vs. 6 percent, $LSD_{0.05}$ = 2 percent). Overall, yield responses for winter wheat entries in these four experiments did not differ when data were grouped over years and locations (Table 2). The entry with the least amount of yield reduction, 'ORSS-1757', had the lowest standard error at both locations during 2008 but at neither location during 2007. CT000330 had a comparatively high response to inoculation but also had the highest standard error in experiments at both locations during 2007. 'Coda', which had an intermediate response to inoculation, had the highest standard error of the mean in experiments at both locations during 2008.

When data for 7 winter wheat varieties were grouped over 9 location-years the main effects were significant for year but not location or variety, indicating that there were large differences among years but no consistent differences between locations or among the winter wheat varieties analyzed in this group (Table 3). The 3-way interaction was significant for year by location by variety, as were the 2-way interactions for year by location and cultivar by location. Yields were reduced greatly during 2002 (58 percent), very little during 2007 (4 percent), and at intermediate

Table 1. Percent yield reduction for 17 spring wheat entries planted into three experiments inoculated with *Fusarium pseudograminearum* at Pendleton (2007 and 2008) and Moro (2007).

Wheat entry	Percent yield reduction*
2-49	3.8 f
Jefferson	4.8 ef
Gala	4.8 ef
Tara 2002	5.8 ef
Sunco	6.0 ef
Macon	6.3 def
CT030799	7.9 cdef
Penawawa	8.0 cdef
CT020615	8.8 bcdef
Alpowa	9.0 bcdef
Wawawai	9.2 bcdef
Seri	9.5 abcde
Calorwa	11.5 abcd
302-5	11.8 abc
Eden	13.5 ab
Otis	13.6 ab
Puseas	14.7 a
mean	8.8

* Comparison of wheat entry yields in inoculated versus noninoculated plots. Means are from three experiments with six replicates at Pendleton during 2008 and seven replicates at Moro and Pendleton during 2007. Data within a column followed by the same letter do not differ at $P = 0.05$ according to the least significant difference test. Mean yield reductions in individual experiments were 15 percent at Moro in 2007, 5 percent at Pendleton in 2007, and 6 percent at Pendleton in 2008.

Table 2. Percent yield reduction for 16 winter wheat entries planted into four experiments inoculated with *Fusarium pseudograminearum* at Pendleton and Moro during 2007 and 2008.

Wheat entry	Percent yield reduction*
ORSS-1757	6.1 a
Stephens	7.0 a
Bauermeister	7.4 a
Bruehl	7.4 a
CT980872	7.4 a
Sunco	7.5 a
Madsen	8.1 a
BURBOT-6	8.3 a
CT000161	8.3 a
Coda	9.4 a
Weatherford	9.5 a
CT000064	9.6 a
Altay 2000	9.8 a
CT000330	11.0 a
Tubbs 06	11.4 a
Eltan	11.8 a
mean	8.7

* Comparison of wheat entry yields in inoculated versus noninoculated plots. Means are from four experiments with seven replicates at Moro and Pendleton during 2007 and 2008. Data within a column followed by the same letter do not differ at $P = 0.05$ according to the least significant difference test. Mean yield reductions in individual experiments during 2007 and 2008, respectively, were 6 percent and 17 percent at Moro and 5 percent and 7 percent at Pendleton.

levels (11 to 16 percent) during the other 4 years; $LSD_{0.05}$ = 4 percent). Mean yield reductions at Moro and Pendleton varied from 52 and 64 percent, respectively, during 2002 to 3 and 4 percent, respectively, during 2007. Yield reductions differed significantly among entries in only 3 of 9 experiments, including at Pendleton during 2000 and at Moro and Pendleton during 2002. During 2000 at Pendleton the yield reductions among winter wheat entries ranged from 3 percent for 'Madsen' to 21 percent for 'Coda'. Reductions among entries during 2002 ranged from 29 percent for 'Sunco' to 70 percent for 'Eltan' at Moro, and from 39 percent for 'Eltan' to 85 percent for 'Coda' at Pendleton. The overall most tolerant entry, 'Sunco', had the lowest standard error of the mean at Pendleton during 2007 and 2008 and at both locations during 2008. However, 'Sunco' was also the most variable wheat entry among the seven replicates at Moro during 2007. 'Coda' was the overall most sensitive entry and was the most variable entry in 3 of 9 experiments and the least variable entry in two other experiments. Likewise, 'Weatherford' and 'Stephens' were each the most and the least variable entries in individual experiments.

The winter wheat data for 9 location-years were also analyzed after excluding the two experiments in which crown rot caused extreme yield reductions during 2002. This additional analysis was based on the assumption that the excessive disease pressure during 2002 may have overwhelmed any inherent differences in crown rot tolerance that may have existed under more typical levels of disease pressure. Main effects in the 7 location-year analysis were significant for year and location but not variety. The 3-way interaction was not significant but the 2-way interactions were significant for year by location. These results indicated that there was no consistent crown rot difference among winter wheat varieties in these 7 experiments (Table 3).

Table 3. Percent yield reduction for 7 winter wheat entries planted into 9, 7, 4 or 6 experiments inoculated with *Fusarium pseudograminearum* over a 9-year period from 2000 to 2008 at Pendleton and Moro.

Wheat	Percent yield reduction*			
variety	9 location-yr	7 location-yr	4 location-yr	6 location-yr
Bruehl	19.5 a	9.5 a	7.4 a	12.3 a
Coda	25.3 a	13.3 a	9.4 a	18.5 a
Eltan	22.1 a	12.9 a	11.9 a	14.2 a
Madsen	20.6 a	9.1 a	8.1 a	10.5 a
Stephens	20.9 a	10.4 a	7.0 a	14.9 a
Sunco	18.0 a	7.8 a	7.5 a	8.2 a
Weatherford	21.0 a	11.4 a	9.4 a	14.0 a
mean	21.1	10.6	8.7	13.2

* Comparison of variety yields in inoculated versus non-inoculated plots. Means for the 9 location-year analysis are for 3 experiments with 3 replicates (20002, 2001 and 2003), 2 experiments with 4 replicates (2002), and 4 experiments with 7 replicates (2007 and 2008).

Means for the 7 location-year analysis were calculated after 2 experiments with exceptionally high disease severity, during 2002, were eliminated from the 9-experiment data set. Data for 4 location-years was from Moro and Pendleton during 2007 and 2008. Data for 6 location-years were only from Pendleton, with experiments performed from 2000 to 2008. Data within a column followed by the same letter do not differ at P = 0.05 according to the least significant difference test.

Analysis of the margin of error

The relationship between the margin of error and the number of observations (Fig. 1) indicated that the least amount of variability occurred in data for experiments that did not include the year (2002) in which disease pressure was extraordinarily high; e.g., the greatest variability occurred in the 6- and 9-location-year groupings. The margin of error for defining the crown rot tolerance reaction for spring wheat entries was 5.3 percent, based on 20 yield comparisons in 3 experiments. The analysis estimated that 24 comparisons, such as in 6 experiments with 4 replicates per treatment, would be required to achieve a level of precision at the 95 percent confidence level. The calculation estimated that 27 observations would be required to achieve tolerance definitions at the 95 percent confidence level for the two winter wheat data sets (4- and 7-location-years) that did not include experiments during 2002, and that about 95 observations would be required if data for 2002 was included in the analysis. Since it is impossible and impractical to test each variety or breeding line 95 times, it was determined that 27 observations were required if the 90 percent confidence level could be accepted as being more reasonable and achievable. However, we also noted that the 90 percent confidence interval for this group of winter wheat entries would be meaningless because this less precise level of accuracy would allow the acceptable range of the phenotypic responses (±10 percent = 20 percent allowable variability in mean yield response) for each entry to be greater than the 7 percent and 11% ranges of yield reductions actually measured in those two experiments.

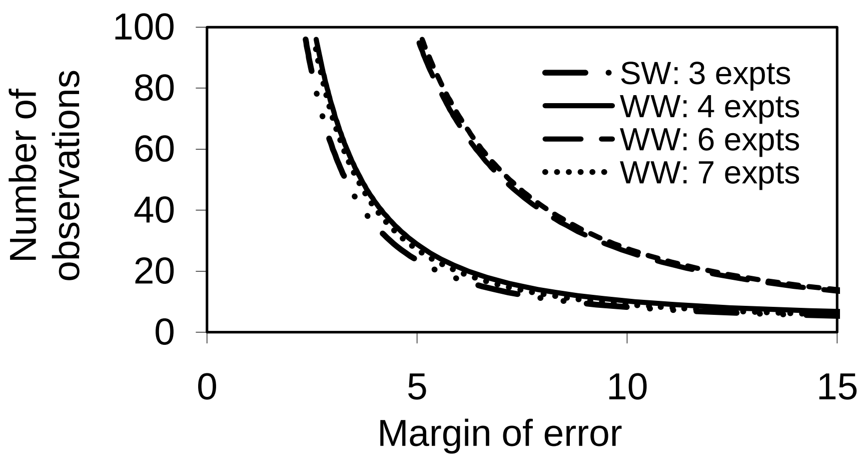

Figure 1. Relationship between number of observations and the margin of error within data sets for five groups of wheat cultivars and breeding lines, based on calculations using standard deviations observed in comparisons of grain yields in native field soil and soil inoculated with *Fusarium pseudograminearum*. The margin of error describes the precision (probability level) at which the crown rot tolerance reaction (phenotypic response) is described for a wheat entry that exhibits an average level of variability in a given number of observations (yield comparisons) in field experiments. Calculations were for groups of 1) 17 spring wheat entries evaluated in 3 ex-

periments with 6 or 7 replications (20 observations per entry), 2) 4 experiments with 16 winter wheat entries and 7 replications (28 observations), 3) 6 experiments with 7 winter wheat varieties and 3 to 7 replications (27 observations) at Pendleton from 2000 to 2008, 4) 7 winter wheat varieties evaluated in 7 experiments with 3 to 7 replications (37 observations) from 2000 to 2008 (data for experiments during 2002 was excluded), and 5) 7 winter wheat entries evaluated in 9 experiments with 3 to 7 replications (48 observations) from 2000 to 2008.

Discussion

This research evaluated the variability of the phenotypic yield response when soils were inoculated with the crown rot pathogen *Fusarium pseudograminearum*. The difference in grain yield in inoculated compared to noninoculated soil was applied as the measure of disease tolerance. The variability of response for each wheat entry was evaluated within individual experiments and when experiments were grouped across years and locations. The comparative yield responses were highly variable within all experiments as well as across locations and years. The range of yield responses to crown rot differed significantly among the 17 cultivars of spring wheat tested during 2007 and 2008 but not among groups of winter wheat entries tested over several years and locations.

The margin-of-error analysis (Bockus et al. 2007) indicated that it is possible to accurately characterize within an acceptable period of time the tolerance characteristics of spring wheat but not winter wheat. The analysis indicated that yield responses for spring wheat could be described with 95 percent confidence using as few as 24 comparisons of yields in inoculated versus non-inoculated soil. This goal could be achieved by conducting as few as six successful spring wheat experiments with four replicates per treatment, or by four experiments with six replicates. It is therefore possible to reliably evaluate advanced breeding lines of spring wheat in a timely manner before some of the lines become registered for use in commerce.

In contrast, we were not able to achieve a similar objective for winter wheat. The higher level of variability in yield response, along with the greater influences of year and location, and the narrower range of yield reductions among winter wheat entries resulted in the estimate that about 95 observations would be required to define the crown rot tolerance characteristic at the 95 percent confidence interval. A program having that objective would be cost prohibitive and unlikely to be capable of accurately screening advanced winter wheat breeding lines before some of the lines are released for commercial production. Defining tolerance levels at a lower level of confidence was also shown to be meaningless.

Research in Australia has successfully evaluated crown rot tolerance for many years. The production cycle in that country averages 6 months from planting to harvest, which is more comparable to spring wheat (5 months) than winter wheat (10 months) in the PNW. Several Australian standards were incorporated into these experiments even though they are not always well adapted to the differences in cultural management to which they are subjected in the PNW, such as planting near the end of the precipitation season in the PNW compared to the beginning of the rainy season in Australia, and planting into soils that are warming during the springtime in the PNW rather than cooling at the beginning of the milder winters in Australia. Nevertheless, the Australian standards performed against crown rot in the PNW as they have been previously characterized in Australia. ‘Puseas’ is an Australian standard for intolerance to crown rot. Standards for tolerance include ‘2-49’ and ‘Gala’. Another Australian standard for tolerance is ‘Sunco’, which carries adult-plant partial resistance and is generally less tolerant than ‘2-49’, which exhibits seedling resistance. In our tests ‘2-49’, ‘Gala’, and ‘Sunco’ were each significantly less affected by crown rot than ‘Puseas’, with ‘Sunco’ being slightly less tolerant than ‘2-49’ and ‘Gala’. The PNW-adapted cultivars ‘Jefferson’ and ‘Tara 2002’ were also comparatively tolerant, ranking between ‘2-49’ and ‘Sunco’. Among the least tolerant PNW entries were ‘Otis’ and ‘Eden’, which ranked similarly to ‘Puseas’. We propose that these four PNW-adapted cultivars be used as tolerant (‘Jefferson’ and ‘Tara 2002’) and intolerant (‘Otis’ and ‘Eden’) standards for future crown rot screening experiments with spring wheat in the PNW.

In spite of many observations made, high variability among varietal responses in our winter wheat experiments made it impossible to establish reliable definitions of crown rot tolerance and intolerance. While ‘Sunco’ was generally among the most tolerant of the entries in winter wheat trials, there were two strong exceptions to that observation; at Pendleton during 2002 and at Moro during 2008. We conclude that the validity of data characterizing tolerance of winter wheat varieties and lines to crown rot should be considered questionable unless the results and interpretations were based on a clearly stated and very large number of observations that spanned multiple testing sites and years.

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Associations among Cropping Systems, Root-lesion Nematodes, and Wheat Yield

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Abstract

Wheat in low-precipitation regions of eastern Oregon and Washington is grown mostly as a rainfed winter wheat-summer fallow rotation with wheat planted into cultivated fallow. There are increasing trends for cultivated fallow to be replaced by chemical fallow and for spring cereals to be planted annually without tillage. Most fields are infested by the root-lesion nematodes *Pratylenchus neglectus* and/or *P. thornei*. A replicated multiyear experiment was conducted at the Sherman Experiment Station at Moro, Oregon to compare cropping systems on soil infested by *P. neglectus*. Populations of *P. neglectus* did not differ in cultivated versus chemical fallow. Lowest populations occurred in annual spring barley. Populations became greater with increasing frequency of the host crops mustard, pea, and wheat. Annual winter wheat had the highest *P. neglectus* populations, the lowest capacity to extract soil water, and a lower grain yield compared to winter wheat rotated with summer fallow or other crops. Winter wheat yield was inversely correlated with the population of *P. neglectus*. Measures to monitor and to reduce the populations of *P. neglectus* in Pacific Northwest wheat fields are recommended.

Keywords: barley, mustard, *Pratylenchus neglectus*, root-lesion nematode, spring wheat, summer fallow, water-use-efficiency, winter pea, winter wheat

Introduction

Root-lesion nematodes (*Pratylenchus* spp.) are present in most of the fields in low-precipitation regions of southern Idaho, eastern Oregon, eastern Washington, and northern Montana (Smiley et al. 2004, Strausbaugh et al. 2004, Johnson 2007;). Effects of crop management practices on these nematode populations have not been clearly defined, although much higher populations were detected in annually cropped fields than in winter wheat-summer fallow rotations. Lower populations following fallow and direct associations between *Pratylenchus* spp. population density and frequency of cereal cropping have also been reported in other countries (Gair et al. 1969, Nombela et al. 1998, Riley and Kelly 2002). Barley is generally considered a poorer host than wheat (Taylor et al. 2000, Smiley et al. 2004, Thompson et al. 2008, Vanstone et al. 2008). Compared to wheat in a lesion nematode-infested soil in Australia, barley was more efficient at extracting soil water and barley yields were more responsive to stored soil moisture in a year with limited in-crop rainfall (Thompson et al. 1995).

Only two species of root-lesion nematodes are prevalent in Pacific Northwest (PNW) dryland fields and both species (*Pratylenchus neglectus* and *P. thornei*) cause substantial constraints to grain yields in rainfed cereals worldwide (Castillo and Vovlas 2007, Smiley and Nicol 2009). Both species have reduced yields of annually cropped spring wheat by as much as 70 percent in the PNW (Smiley et al. 2005a,b) but these studies did not compare effects of various crop management systems on these species. Smiley et al. (2004) reported presumptive evidence that yield of winter wheat was reduced by *P. neglectus* but the effects of potential variations in the amount of stored soil water in the rotations were not examined in that study.

Ninety percent of the winter wheat acreage in eastern Oregon and Washington is managed as a winter wheat-summer fallow rotation. Most of the summer fallow acreage is managed as cultivated dust mulch but chemical fallow is becoming increasingly popular. Three-year rotations of winter wheat, a spring crop, and chemical fallow also are of interest but have not yet been widely adopted because they are often less profitable even though they have less year-to-year economic risk compared to the winter wheat-summer fallow systems. Direct-seeded fields planted annually to spring crops are also becoming increasingly practiced in the low-precipitation region. However, fields planted annually to no-till spring crops are planted mostly to wheat or barley because these small grain crops are generally more profitable than rotations that include broadleaf crops such as yellow mustard or canola. While increasingly important, annual no-till spring cropping is not yet widespread because it is less profitable than the winter wheat-summer fallow rotation (Juergens et al. 2004; Schillinger et al. 2006a,b; Machado et al. 2007; Bewick et al. 2008). In continuous annual cropping systems near Pendleton, Oregon, spring barley produced 34 percent and 45 percent greater yields than spring wheat in cultivated and direct-drill systems, respectively, as well as 25 percent and 5 percent greater yields than winter wheat-summer fallow rotations with cultivated and chemical fallow, respectively (Machado et al. 2007).

A replicated long-term experiment was established during 2003 to examine multidisciplinary aspects of eight cropping systems at a low-precipitation site known to be infested with *P. neglectus*. This paper is an abbreviated version of a technical paper (Smiley and Machado 2009) in which we reported associations between cropping systems, nematode populations, grain yields, and water extraction over the first 5 years of the long-term experiment at Moro.

Materials and Methods

The experiment was performed at the Columbia Basin Agricultural Research Center at Moro, in Sherman County, Oregon. The site averaged 11 inches annual precipitation over the past 10 years and the soil is a moderately deep (mostly more than 40 inches) Walla Walla silt loam.

Field operations

Management of the experimental area was described in a previous report (Machado et al. 2008). Briefly, a uniform crop of spring wheat was planted over the intended experimental area during 2003. The experimental area was mapped into 42 plots (each 48 by 350 ft) arranged as 3 replicated blocks where each contained 14 plots representing 8 crop treatments. Numbers of plots (14) in each replicate were greater than the number of crop treatments (8) because each phase of each multiyear crop treatment was present in all years to allow treatment data to be collected for each year. The eight treatments included annual winter wheat; annual spring wheat; annual spring barley; winter wheat-summer fallow rotation with either cultivated or chemical fallow; a 2-year rotation of winter wheat and winter pea; a 3-year rotation of winter wheat, spring barley, and chemical fallow; and flexible cropping (flex crop) to allow annual flexibility in selecting the crop species produced. Flex-cropping decisions were made by an advisory committee made up of the project leader and producers, and were based on market prices, soil moisture available before planting, and occurrences of weeds and diseases. Two flex-crop treatments included winter wheat, chemical fallow, and spring-planted crops of barley, camelina, pea, mustard, and wheat.

Seven of the eight crop treatments were managed without tillage (no-till) using direct-drill technology. All direct-drill treatments were planted using a Fabro disk-type drill with 12-inch row spacing. A blend of urea and ammonium sulfate was banded 1 inch below the seed of all direct-drill small grains crops at application rates based on industry standards and results of annual soil tests by commercial laboratories. Herbicides were applied to all crop treatments during the growing season in accordance with weed populations and industry standards.

Direct-drill spring wheat and spring barley occurred in the annual crop sequences and in the 3-year and flex-crop rotations (Table 1). These crops were planted in April. Cultivars of spring wheat included 'Zak' in 2004 and 2005, and 'Louise' from 2006 to 2008. The spring barley cultivar was 'Camas' from 2004 to 2007 and 'Haxby' during 2008. Direct-drill winter pea occurred in the 2-year rotation and was planted during October or November. Cultivars were Line PS9430706 in 2004 and 'Spector' from 2005 to 2008. Granular Nitragin® inoculant was applied with the seed and starter fertilizer (10 lb N/acre) was banded below the seed at a depth of 3 inches. Direct-drill spring camelina (cv. 'Calena'), spring mustard (cv. 'Tilney') and spring pea (cv. 'Universal') were planted into flex-crop treatments during April.

Direct-drill winter wheat occurred in the annual and wheat-fallow sequences, the 2- and 3-year rotations, and in flex-crop rotation no. 2 (Table 1). Plots to be planted to direct-drill winter wheat were sprayed once in late September or early October with glyphosate to control summer weeds. Glyphosate was also applied to control weeds two to three more times during the spring and summer of the fallow phase of the direct-seeded biennial winter wheat treatment managed with chemical fallow. Direct-drill winter wheat was planted in October or November. Cultivars were 'Tubbs' in 2004, 'Stephens' in 2005, and 'ORCF-101' from 2006 to 2008.

Compared to direct-drill treatments, management of the winter wheat-summer fallow treatment differed considerably when planted into cultivated fallow. After the wheat crop was harvested the plots were not cultivated until mid-April of the following year. Glyphosate was applied as needed in the fall and spring. In April, primary tillage was conducted to a depth of 6 inches using a John Deere 1600 cultivator fitted with chisel plow turning points, followed by sweep cultivation to a depth of 5 inches using the JD 1600 equipped with 12-inch-wide sweeps. Plots were rod-weeded at a depth of 3 to 4 inches whenever necessary to maintain weed control and the dust mulch fallow. Plots were generally rod-weeded two or three times between May and August. In accordance with industry standards and based on soil sampling, anhydrous ammonia and gypsum were incorporated into fallow treatments during September to meet soil fertility requirements. Winter wheat was planted in mid-September using a John Deere 7616 HZ drill with 16-inch row spacing. Cultivars were the same as for direct-drill winter wheat.

All crops were harvested as a strip following the centerline of each 48-ft-wide plot using a commercial combine with an 18-ft header. Grain yield was measured using a weigh wagon to determine yield per plot.

Soil water

Measurements of soil water content were conducted throughout the 2006 and 2007 growing seasons using a PR2 probe (Delta-T Devices Ltd., Cambridge, England). Access tubes were inserted by extracting a soil core using a tractor-mounted Giddings Hydraulic Soil Sampler. The PR2 probe senses soil moisture content (percent volume) at 4-, 8-, 16-, 24-, and 40-inch depths by responding to dielectric soil properties. Readings were made on two access tubes located 45 ft apart in each plot. Three measurements were recorded at each reading, with the probe rotated to a different direction for each measurement.

Routine soil sampling and nematode extraction

Soil was collected each year to assess *P. neglectus* populations in individual treatments during mid-March to mid-April, when soil was moist shortly before or after spring crops were planted. Samples consisted of 20 cores (1 inch diameter) composited for each of the 42 plots. Samples were collected to 6-inch depth during 2004 and 2005. Sampling was changed to 12-inch depth during 2006 to 2008 after we learned that deeper sampling was necessary to adequately quantify populations of lesion nematodes in wheat-fallow rotations (Smiley et al. 2008). Samples were transported to Western Laboratories in Parma, Idaho for nematode extraction and quantification.

Profile depth sampling

Soil cores were collected from all plots during 2008 using the Giddings Hydraulic Soil Sampler with a 2-inch-diameter, 5-ft-long slotted soil tube and heavy-duty bit. Soil cores were collected to 4-ft depth and separated into 12-inch intervals. A pair of soil cores was collected 3 ft apart at each sampling location to ensure sufficient soil was collected for each depth interval and to minimize the effect of the inherent spatial variability of the nematodes. Corresponding depth intervals from the pair of cores taken from each sampling location were composited into individual samples. Nematodes in each soil depth interval were extracted and quantified.

Statistical analysis

Nematode data were transformed using $\ln(x + 1)$ to normalize population estimates prior to statistical analysis. Results were analyzed using one-way analysis of variance (ANOVA) and the logarithmic means were then back transformed into real numbers for presentation. Grain yields were also analyzed by ANOVA. Long-term effects of rotations were evaluated by grouping grain yield and nematode data over years. Subsets of the data were also evaluated. Examples of subsets included soil-sampling depth intervals grouped across crop treatments, or crop treatments grouped according to the crop or field management treatment immediately preceding a soil sampling date, or the two crops or management treatments before samples were collected. Associations of grain yields and nematode populations, and results of hand sampling versus mechanized core sampling procedures to assess nematode populations were evaluated by regression analysis.

Results

The only plant-parasitic nematode considered capable of affecting plant health in this experiment was *Pratylenchus neglectus*. Numbers of this species were vastly greater than for any other plant-parasitic species. Populations averaged over the 5-year sampling period revealed that highest average numbers corresponded in general with the frequency of host crops (wheat, pea, and mustard) in the crop sequence. The highest average (Table 1) occurred in annual winter wheat and annual spring wheat, the 2-year wheat-pea rotation, the winter wheat-summer fallow sequences in which wheat was produced in 3 of 5 years, and in the flex-crop rotation no. 1, in which spring wheat and spring mustard were produced in 3 of 5 years. The lowest numbers occurred in annual spring barley, the winter wheat-summer fallow sequences in which wheat was produced in only 2 of 5 years, and in the 3-year rotations in which wheat was produced in only 1 or 2 of 5 years.

Populations of *P. neglectus* were also analyzed to determine effects of the preceding crop or fallow treatment from 2005 to 2008. Populations after spring barley and fallow were about half the populations following wheat or pea (Table 2). The influence of spring mustard on populations of *P. neglectus* was intermediate between wheat and barley. Compared to annual winter wheat, populations of *P. neglectus* diminished when winter wheat was rotated with either chemical or cultivated fallow— the type of fallow had no effect on nematode populations.

Results of deep core data collected from the 42 plots during 2008 revealed low numbers (less than 140/lb of soil) of *P. neglectus* were detected throughout the profile of annual spring barley (Fig. 1). Populations were higher in annual spring wheat and annual winter wheat but the peak population density was about 12 inches deeper in the profile for winter wheat than for spring wheat. Populations of *P. neglectus* were particularly high following sequences of spring mustard and spring wheat, and of winter pea and winter wheat.

Populations of *P. neglectus* also were analyzed by grouping the 12-inch depth intervals across crop sequences and analyzing the data. Significantly higher populations ($LSD_{0.05}$ = 370/lb of soil) occurred in the first and second foot intervals (1,600/lb and 2,000/lb, respectively) than in the third (715/lb) and fourth foot (186/lb) intervals. Results of data collected in the surface foot of soil were comparable ($R^2 = 0.64$, $P < 0.0001$) for three pairs of deep cores collected by hydraulic sampler and 20 cores collected by manual sampling.

When data were grouped over the entire 4-ft-profile depth and also across each phase of each crop treatment, the average number of *P. neglectus* was significantly higher in flex-crop rotation no. 1 (1,672/lb of soil), the 2-year wheat/pea rotation (1,590/lb) and winter wheat-chemical fallow (884/lb) compared to the annual spring barley (79/lb) and 3-year rotation (317/lb).

As expected, grain yields were affected by precipitation. Total precipitation for crop years 2003, 2004, 2005, 2006, 2007 and 2008 was 9.3, 11.9, 7.9, 16.9, 11.1, and 8.7 inches, respecttively, which corresponded with generally lower yields during 2005 and 2008. Grain yield also differed significantly among treatments during 2004 (Table 3) but the result was considered to have no importance with respect to crop rotation effects being investigated because 2004 was

Table 1. Crop management treatments and number of lesion nematodes in the top foot of soil during 5 years of 8 cropping systems at Moro, Oregon.

	Harvested crop or field management[a]					*P. neglectus*/lb of soil[b]					
Crop sequence	*2004*	*2005*	*2006*	*2007*	*2008*	*2004*	*2005*	*2006*	*2007*	*2008*	*mean*
Annual spring barley	SB	SB	SB	SB	SB	135 a	1,095 a	214 bcd	314 cd	188 e	285 b
Annual spring wheat	SW	SW	SW	SW	SW	112 a	1,287 a	513 abc	1,644 ab	3,928 ab	864 ab
Annual winter wheat	WW	WW	WW	WW	WW	260 a	1,271 a	1,420 a	2,029 a	2,671 ab	1,206 a
Winter wheat-chem. fallow	WW	ChF	WW	ChF	WW	1,727 a	408 a	492 abc	1,333 ab	2,139 abc	998 ab
Winter wheat-chem. fallow	ChF	WW	ChF	WW	ChF	192 a	188 a	98 d	333 cd	1,665 abcd	288 b
Winter wheat-cult. fallow	WW	CuF	WW	CuF	WW	622 a	2,236 a	426 abc	1,479 ab	1,489 abcd	1,055 a
Winter wheat-cult. fallow	CuF	WW	CuF	WW	CuF	275 a	391 a	447 abc	311 cd	1,109 abcd	440 ab
2-year rotation	WW	WP	WW	WP	WW	381 a	674 a	540 abc	2,455 a	5,024 a	1,113 a
2-year rotation	WP	WW	WP	WW	WP	152 a	616 a	769 ab	1,031 abc	3,330 ab	757 ab
3-year rotation[c]	WW	SB	ChF	WW	SB	270 a	857 a	402 abcd	169 d	423 de	366 ab
3-year rotation	SB	ChF	WW	SB	ChF	322 a	160 a	155 cd	982 abc	857 bcde	368 ab
3-year rotation	ChF	WW	SB	ChF	WW	530 a	851 a	742 ab	758 abc	545 cde	673 ab
Flex-crop rotation no. 1[d]	SB	SW	SM	SW	SP	349 a	1,055 a	305 bcd	836 abc	3,504 ab	800 ab
Flex-crop rotation no. 2	SW	SB	ChF	WW	SC	208 a	674 a	701 ab	500 bcd	1,274 abcd	575 ab

[a] ChF = chemical fallow, CuF = cultivated fallow, SB = spring barley, SC = spring camelina, SM = spring mustard, SP = spring pea, SW = spring wheat, WP = winter pea, WW = winter wheat. The experimental area was planted uniformly to spring wheat in 2003. All except the winter wheat-cultivated fallow treatment were direct seeded, e.g., no-till.

[b] Means followed by the same letter within a column are not significantly different at $P = 0.05$. All crops and fallow treatments were sampled shortly before or after spring crops were planted during March. Therefore, crops planted during the autumn were "in-crop" for 5 months prior to sampling.

[c] Winter wheat plots in the 3-year rotation were very dry and compact in 2007. Low numbers of *P. neglectus* in those three plots may be biased by a shallower sampling depth during 2007.

[d] Flex crop = rotational sequences were determined annually based on available stored water, crop prices, weeds, and diseases.

Table 2. Average number of lesion nematodes in the top foot of soil during the spring following harvest of a specific crop or following a fallow management treatment over the 4-year interval 2005 to 2008 in 8 crop sequences at Moro, Oregon.

Previous crop or management [a]	*P. neglectus*/ lb of soil [b]
Spring wheat (21)	1,174 a
Winter pea (12)	1,145 ab
Winter wheat (63)	1,035 ab
Spring mustard (3)	836 ab
Cultivated fallow (12)	527 ab
Chemical fallow (30)	441 b
Spring barley (27)	440 b

[a] Data are the means of the total number of times each crop or fallow management sequence occurred (shown in parenthesis) over the 4-year interval in 8 cropping sequences.

[b] Means followed by the same letter are not significantly different.

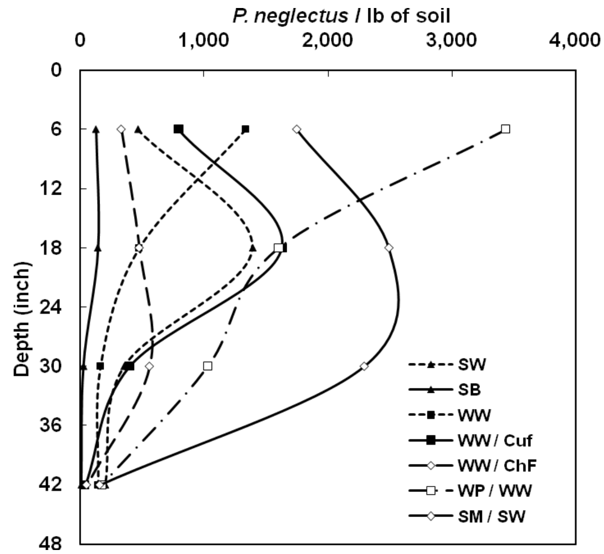

Figure 1. Distribution of lesion nematodes at 1-ft depth intervals to a depth of 4 ft in 7 crop sequences in the long-term experiment at Moro, Oregon during April 2008: direct-drill annual spring wheat (SW), spring barley (SB), or winter wheat (WW), direct-drill spring wheat after spring mustard (SM/SW), winter wheat alternated with either cultivated fallow (WW/CuF) or chemical fallow (WW/ChF), and winter wheat rotated with winter pea (WP/WW).

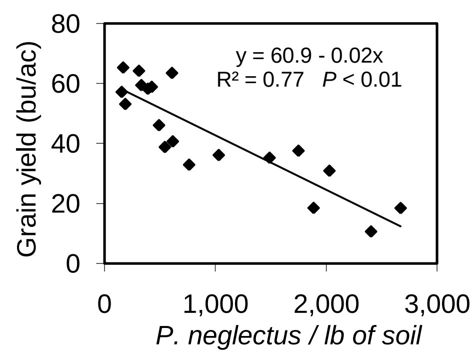

Figure 2. Relationship between numbers of lesion nematodes and grain yields for winter wheat in 5 crop rotations over 4 crop years, 2005-2008; treatments include annual winter wheat, winter wheat rotated with either cultivated or chemical fallow, 2-year winter wheat-winter pea rotation, and 3-year winter wheat-spring barley-chemical fallow rotation.

Table 3. Grain yield for wheat and barley crops produced over 4 crop years in 8 crop sequences at Moro, Oregon. All plots were direct seeded (no-till) except winter wheat in the cultivated fallow treatment.

Crop and crop sequence[a]	2004[b]	2005	2006	2007	2008	4-yr mean
Spring barley			*grain yield (lb/acre)*			
Annual spring barley	3,420 a	731 c	4,002 a	2,475 d	1,409 c	2,155 b
3-year rotation	2,557 c	803 c	3,651 a	2,255 de	587 e	1,824 bc
Flex-crop rotations[c]	2,633 c	848 bc				-
Spring wheat						
Annual spring wheat	2,983 c	765 c	2,856 bc	2,423 e	1,013 d	1,764 bc
Flex-crop rotations[c]	2,799 c	975 c		2,195 f		-
Winter wheat						
Annual winter wheat	3,853 ab	801 c	1,394 d	2,329 ef	1,390 c	1,479 c
Winter wheat-chemical fallow	3,698 ab	4,007 ab	3,475 b	4,482 b	2,832 ab	3,699 a
Winter wheat-cultivated fallow	3,640 b	4,391 a	4,439 a	4,842 ab	2,656 b	4,083 a
2-year rotation	3,674 ab	3,068 ab	2,481 c	2,723 de	897 d	2,291 b
3-year rotation	3,792 ab	4,788 a	4,311 a	4,925 a	2,925 a	4,238 a
Flex-crop rotation no. 2[c]				3,898 c		-

[a] Grain yields in eight crop sequences.

[b] Means followed by the same letter within a column are not significantly different at $P = 0.05$. The 4-year mean is of grain yields for crops harvested during the last 4 years, 2005-2008.

[c] Flex crop = rotational sequences were determined annually based on available stored water, crop prices, weeds, and diseases.

the first rotational sequence following a uniform crop of spring wheat during 2003. In 2005 spring crops fared poorly due to drought. Highest yields were produced by winter wheat in the 2- and 3-year rotations and in the winter wheat-cultivated fallow treatment. During 2006 spring barley in the annual crop sequence and in the 3-year rotation produced yields statistically equivalent to winter wheat-cultivated fallow and winter wheat in the 3-year rotation. The lowest yields in 2006 were for annual winter wheat and winter wheat in the 2-year rotation. In 2007 the highest yields were from winter wheat in the 3-year rotation and in the winter wheat-cultivated fallow. The lowest wheat yield during 2007 was the spring wheat in flex crop no. 1, following a sequence of spring wheat and spring mustard. During 2008, annual spring barley produced more grain than annual spring wheat but was equal to the amount of grain produced in the annual winter wheat treatment. The highest producing winter wheat occurred in the winter wheat-summer fallow sequences and the 3-year rotation.

Mean grain yields over the 3 crop years 2005 to 2007 (Table 3) indicated that the highest yields were achieved for winter wheat in the 3-year rotation and in the winter wheat-cultivated fallow. These highest-yielding treatments were followed, in order of decreasing yield, by winter wheat-chemical fallow, winter wheat in the 2-year rotation, annual spring barley, spring barley in the 3-year rotation, annual spring wheat, and annual winter wheat. The yields for winter wheat in five crop sequences (all except the flex crops) from 2005 to 2008 were strongly and negatively correlated with populations of *P. neglectus* in the upper foot of soil during the spring (Fig. 2).

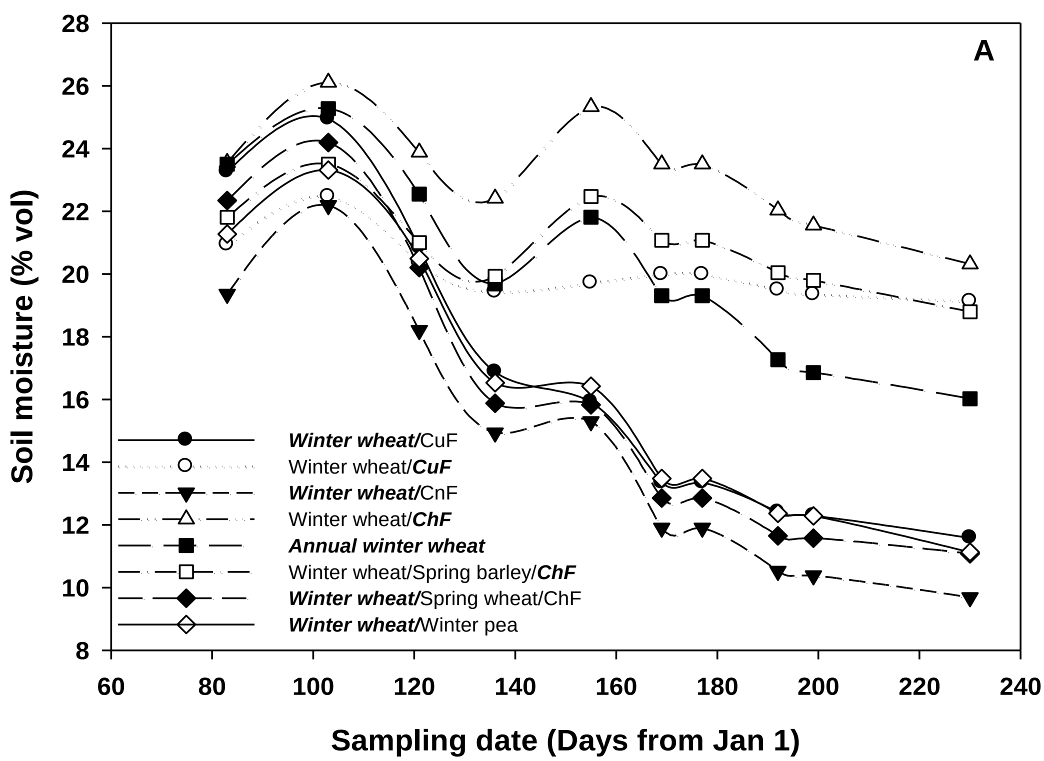

Figure 3. Mean soil water content under all rotations in the 0- to 4-ft depth profile at Moro from March to September during 2006. Data are for the crop or treatment shown in boldface and italics of a crop or management sequence; CuF = cultivated fallow and ChF = chemical fallow.

Soil water content was monitored in the profiles of each crop sequence during the spring and summer of 2006 and 2007. Three soil moisture patterns were evident during 2006 (Fig. 3). Greater moisture was present at the end of the growing season for the three fallow treatments compared to all winter wheat treatments except annual winter wheat, which was intermediate between the fallow treatments and winter wheat in other crop sequences. Compared to winter wheat in other crop sequences, the annual winter wheat extracted a lower amount of water from soil and had the greatest population of *P. neglectus* (Table 1) and lowest grain yield (Table 3). The relationships between soil moisture extraction, nematode populations, and relative grain yields were similar although slightly less pronounced during 2007.

Discussion

Population densities and the vertical distribution of the root-lesion nematode, *Pratylenchus neglectus*, in soil profiles were strongly influenced by cropping systems. The lowest populations were detected when barley was planted annually and the highest populations occurred when winter wheat was planted annually or rotated with winter pea. These results are in agreement with the recognition of barley as generally more tolerant and more resistant than wheat to *P. neglectus* and *P. thornei* (Taylor et al. 2000; Smiley et al. 2004, 2008; Thompson et al. 2008; Vanstone et al. 2008). Our findings are also in agreement with previous observations that *Pratylenchus* species become more numerous as host-crop frequency is increased (Gair et al. 1969, Riley and Kelly 2002). Although Strausbaugh et al. (2004) detected fewer lesion nematodes in chemical than cultivated fallow, no differences between fallow type were detected in this study or by Brmež et al. (2006) or Smiley et al. (2004). Likewise, observations near Heppner indicated that the *P. neglectus* population was comparable following mustard and wheat (Smiley et al. 2008). However, it was unexpected that *P. neglectus* populations in the winter wheat/winter pea rotation would be comparable to those in rotations containing known "good" host species (Thompson et al. 2008, Vanstone et al. 2008) every year, as in annual winter wheat and annual spring wheat. Field pea was resistant to *P. neglectus* in Australia (Vanstone et al. 2008) but was associated with high populations of *Pratylenchus* species in the PNW (Riga et al. 2008). The role of pea in developing high populations of lesion nematodes needs to be examined in greater detail.

Winter wheat is typically planted into cultivated fallow during September and into chemical fallow during October. Seedlings become established and reach the second through fourth leaf stage before onset of semi-dormancy during winter. Active seedling growth resumes during early spring at a time when spring cereals are being planted. Soil sampling to assess nematode populations in this experiment was performed as spring cereals were being planted. Populations of nematodes detected in winter wheat during the spring, 6 months after the wheat was planted, were numerically higher in the fallow phase than the "in-crop" phase in 4 out of 10 comparisons and were significantly lower than the "in-crop" phase in only 1 of 10 comparisons. An identical phenomenon, with fewer comparisons, also occurred in multiyear samplings of wheat and fallow near Heppner (Smiley et al. 2008). It is common for most lesion nematodes to inhabit roots during periods of active root growth, to move into and out of roots throughout active root growth, and to become more prevalent in soil during periods when soil is moist but without the presence of a living host (Castillo and Vovlas 2007).

Smiley et al. (2004) reported that lesion nematode populations inside cereal roots were lowest during the spring (May) and increased to a maximum as mature roots died before harvest in July. Populations detected in soil were lowest during June and July and highest during October, after roots had died and new tissue was not yet available for recolonization. Smiley et al. (2004) also observed that *Pratylenchus* spp. became active colonists of volunteer cereals and grass weeds (mostly downy brome [cheatgrass]) that were stimulated into seed germination and seedling growth following the onset of rain during the autumn. They found lesion nematode populations in roots of volunteers and grass weeds during October to be comparable to populations in planted spring and winter cereals the following May. *Pratylenchus* species are hosted by a large and diverse number of plant species (Castillo and Vovlas 2007, Vanstone et al. 2008). As with most commercial winter wheat-summer fallow practices, winter wheat stubble in this experiment was not treated with herbicide or tillage from early autumn (October) until the following spring (March-April). An interval of zero to several weeks separated the spring weed management program and collection of samples to assess nematode populations in all treatments, including the fallow. Although populations of lesion nematodes were not monitored in the volunteer cereals and weed grasses in this experiment, there was ample opportunity for multiplication of nematodes through the 10-month winter wheat growth cycle and also, when temperatures permitted, for as many as 7 months of the 14-month “fallow” cycle. We conclude that management of lesion nematodes in the winter wheat-summer fallow region must include eliminating the potential for them to multiply during the fallow period. In soils infested with these nematodes, living plants must not be allowed to persist during the intervals between planted crops.

The vertical distribution of lesion nematodes is highly variable and influenced by such factors as root distribution and soil moisture, temperature, texture, and depth. Sampling to 4- to 6-inch depths is sometimes considered adequate in shallow soils but peak populations are known to occur at considerably greater depth in some deep soil profiles. Smiley et al. (2008) reported that sampling to 12-inch depth always detected more than 50 percent of the lesion nematode population in profiles of silt loams in Oregon. Also, sampling to 18-inch depth detected more than 75 percent of the population in at least 75 percent of samples evaluated. Deep-core samplings per-formed during this experiment revealed that 12-inch-deep samplings enabled us to detect an average of 36 percent (range of 16 to 63 percent) of the total lesion nematode populations in the crop rotations examined. The mean detection level was 81 percent (range of 74 to 87 percent) when samples were collected to a depth of 2 ft. Although a sampling depth of 12 inches was minimally acceptable for comparing lesion nematode numbers among crop management treatments in these deep silt loam soils, a sampling depth of 18 inches was much more informative. Distinguishing nematode populations at a high level of precision, as needed to accurately deter-mine effects of cropping systems, will continue to require laborious and expensive sampling to at least 2-feet depths and segmenting the soil cores into 6- to 12-inch intervals prior to extracting the plant-parasitic nematodes.

Pratylenchus neglectus and *P. thornei* were only recently reported as being common and in high numbers in many fields of the low-precipitation regions of the PNW (Smiley et al. 2004, Strausbaugh et al. 2004), and potential impacts of these species on yield of spring wheat were discussed (Smiley et al. 2005a,b). Presumptive evidence that lesion nematodes also restricted yields of winter wheat was reported (Smiley et al. 2004) but that observation did not provide evidence that the wheat yield was not also influenced by availability of stored soil water, even though the experiment was performed on a shallow silt loam soil between Pilot Rock and Pendleton, where all stored water would be expected to be extracted by each crop each year. In this paper we report that high populations of lesion nematode were associated with reduced yields of winter wheat, and that the greatest yield reduction occurred in the rotation where the least amount of water was extracted during the growing season. Thompson et al. (1995, 2008) previously reported that roots affected by lesion nematodes were less capable of extracting water and plant nutrients, and became prematurely moisture stressed, particularly towards the end of the growing season or in dry years. Wheat in the PNW often receives little effective rainfall late in the growing season and generally depletes stored water in the soil profile before plant maturity. It is now clear that root dysfunction caused by lesion nematodes reduces the capacity of plants to extract deeply stored water late in the growing season. Cropping systems that lead to the highest lesion nematode populations become least efficient for extracting deeply stored soil water.

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Do High Velocity Water Flow Paths Develop Over Time Under No-till?

Stewart B. Wuest, Tami Johlke, and Wes Matlock

Abstract

Water flow through soil is not uniform. Preferential flow paths, where water moves downward much faster than in the surrounding soil, are common in both tilled and untilled soil. We used a 10-min pulse of dye to mark preferential flow paths to learn more about the role of preferential flow in improving water infiltration under different tillage systems. Small cores were taken from dyed and undyed soil at 4- to 10-inch depth. Compared to bulk soil, preferential flow zones had fewer small aggregates, greater water content, and lower bulk density. Root mass and total soil carbon were not significantly different. The same relative differences were found in both tilled and untilled soil. This means infiltration rates in untilled soil were greater despite greater bulk density in both preferential flow zones and the non-preferential-flow matrix soil. These results suggest that greater water flow in untilled soil is not due to better developed preferential flow pathways, but rather to more potential pathways being well connected to the surface water source. This could have more to do with better aggregation of surface soil than with specific properties of the preferential flow paths.

Keywords: no-till, preferential flow, soil bulk density, tillage, water infiltration

Introduction

Preferential flow is recognized as a common feature of water movement in soil (Radulovich et al. 1992, Flury et al. 1994). Recommendations for soil management practices that minimize water runoff could be improved if preferential flow pathways were better understood. A better understanding would also allow more accurate modeling of water movement in soil by improving mechanistic descriptions of tillage effects (Strudley et al. 2008). Indirect methods are often used to detect preferential flow, and specific measurements characterizing zones of preferential flow are commonly lacking (Strudley et al. 2008).

Several studies have provided insight into the nature of preferential flow. Dyed water is sometimes used to mark the flow of water. Different tillage methods have produced different dye patterns, both in the tilled zone and below it (Petersen et al. 2001). In a tilled soil, Omoti and Wild (1979) found dyed zones had low bulk density and sometimes very small fissures. They concluded from the soil they studied that bulk density was more important than earthworm channels in relation to the presence of dye. In a forest soil, Bundt et al. (2001) found that water content was greater in preferential flow zones even 1 day after applying water at low rates. The preferential flow zones also had greater concentrations of organic substrates and nutrients compared to bulk soil.

Roots can create channels for preferential flow, and their effect may vary depending on whether they are alive or dead (Gish and Jury 1983). Roots are a possible mechanism for increases in soil carbon and water-stable aggregates in preferential flow zones. If preferential flow is related to roots in an untilled soil, it seems likely that preferential flow capacity might increase with time through the increase in root growth by perennial plants, establishment of new roots, and perhaps even re-establishment of roots in former root channels in annual plant systems.

Preferential flow appears to be a major factor involved in high infiltration rates under long-term no-till cropping systems in silt loam loess of the Pacific Northwest (Wuest 2005). Another factor correlated to high infiltration is the degree of surface soil aggregation (Wuest et al. 2005). Water-stable aggregates in the uppermost surface soil are controlled by organic carbon levels and can be significantly increased in less than 7 years when converting from intensive tillage to no-till. Preferential flow associated with capacity for very high infiltration rates, however, appears to take decades to fully develop (Wuest et al. 2006).

In Pacific Northwest silt loam soils, preferential flow zones appear to be distinct areas of high water flow, which presumably are active repeatedly over a season or even years where the soil is not significantly disturbed. The number of zones encountered in a soil cross section was greater in untilled soil, and this corresponded to greater ponded infiltration rates (Wuest 2005, Wuest et al. 2006). This leads to the question of how preferential flow zones develop and what their most important characteristics are. It is possible that positive feedback mechanisms are involved, where improved water availability or lower bulk density improves root growth, which in turn increases carbon substrates for soil aggregation and nutrient turnover, which further improves the environment for root growth.

This hypothesis could be tested by following flow zones over time, but it is difficult to make repeated measurements of flow paths over time because the most straightforward method to identify and measure them is marking with dyed water and destructive sampling. Another approach is to use destructive sampling to compare preferential flow zones in a tilled soil to those in an untilled soil. At the same time, the characteristics of preferential flow zones can be compared to bulk soil. This study was conducted to test the hypothesis that preferential flow zones in a silt loam soil would differ from the rest of the soil in measurements of bulk density, soil carbon, soil aggregation, and root mass. We also hypothesized that preferential flow zones in untilled soil would be more developed than in tilled soil.

Materials and Methods

The experimental plots were located near Pendleton, Oregon (45°43'N, 118°38'W, elevation 1,500 ft). Annual precipitation averages 17 inches and falls mostly between October 1 and May 1. Summers are hot and dry. The soil was Walla Walla silt loam (coarse-silty, mixed, superactive, mesic Typic Haploxeroll containing about 10 percent clay, 69 percent silt, and 21 percent fine to very fine sand). Samples were taken from plots of two separate ongoing experiments. The first was a continuous winter wheat (*Triticum aestivum* L.) experiment with 3 treatments: 1 untilled for 7 years and 2 using disk tillage. The second experiment was a pea (*Pisum sativum* L.)–winter wheat rotation established in 1941 (Wuest 2001). Two tillage treatments sampled in this second experiment were plowing before planting for both spring pea and winter wheat, versus no-tillage planting for both crops. Each experiment had four replications. Measurements were made in winter wheat plots in the spring, after winter rainfall had reconsolidated the effects of tillage.

Two sets of samples were collected using dye to identify preferential flow paths, one from each of the two experiments. Soil bulk density, water content, aggregates, and root mass were measured. A third set was collected using sodium iodide as a tracer so data could be obtained for organic carbon without contamination by carbon contained in the dye. This third set of samples was taken from the pea–winter wheat experiment.

We made single-ring infiltration measurements (Bertrand 1965) using 8-inch-diameter cylinders. Row spacing of the wheat crop was 10 inches, and cylinders were always placed to include one crop row inside the cylinder. Cylinders were driven into the soil about 10 inches, and the soil around the inner circumference tamped with a thin plot stake to seal any gaps between the cylinder wall and the soil column. The water level was maintained at approximately 2 inches above the average soil surface for 2 hours.

Preferential flow zones were identified by adding a pulse of Brilliant Blue dye (C.I. Food Blue 2; C.I. 42090; for characteristics see Flury and Fluhler 1995) and potassium bromide. Following 2 hours of ponded infiltration, the dye solution was mixed with the water in the top of the cylinder and left to infiltrate for 10 min. At the end of the 10-min period, remaining water was suctioned off with a vacuum hose. We then immediately excavated the cylinder and took samples from specific depths (Fig. 1). Volumetric samples were taken with a 0.7-inch-inner-diameter by 0.8-inch-long, sharpened, thin-wall metal cylinder (0.31 inch^3 measured volume). Two samples were taken from dyed soil, and two from un-dyed soil.

As previously mentioned, sodium iodide was used as a second tracer method in the untilled pea–winter wheat plots using the method of van Ommen et al. (1988). A total of 88 samples were taken using the iodine tracer. These samples were analyzed for root mass, water content, and total carbon, but not water-stable aggregates.

To process the core samples, sample wet weight was recorded before transferring to a 1,000-µm sieve (1,000 µm = 1 mm), under which were a 250-, a 125-, and a 53-µm sieve, all spaced about 1-cm apart vertically. The entire sieve set was immersed in 300 ml deionized water until the soil sample was completely covered, then immediately sieved for 3 min at 20 cycles per minute and 1.3-cm stroke. This stroke and duration was sufficient to clear the screens of slaked soil, leaving only separated aggregates too large to pass through each sieve. Roots were collected from the 1,000-µm screen after crushing and washing any aggregates remaining on the screen. Roots were then dried at 104°F and weighed.

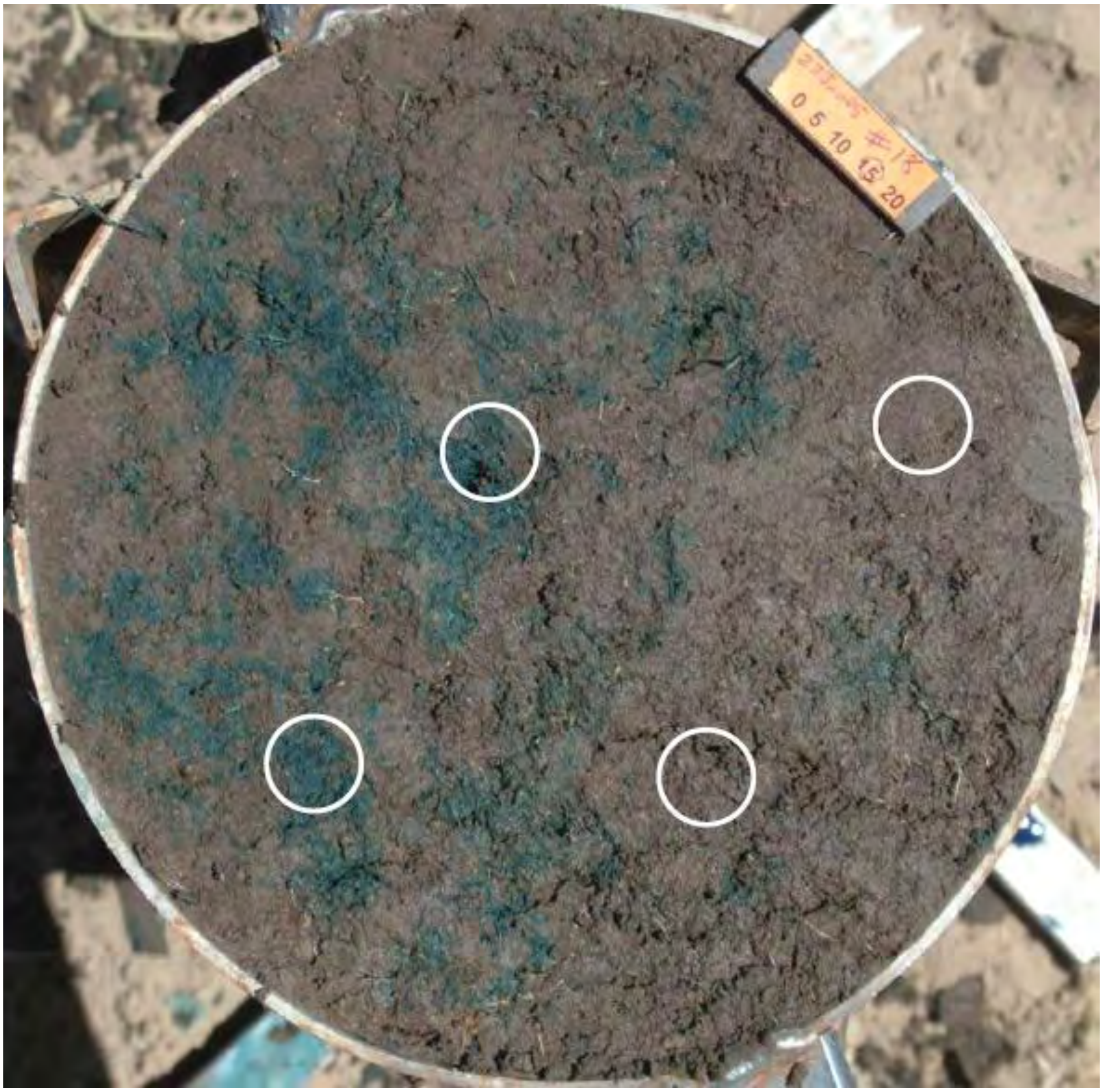

Figure 1. Example of an 8-inch-diameter infiltration cylinder cross-section at 6-inch depth from an untilled plot in the continuous winter wheat experiment. Blue areas (visible only in color reproduction) are preferential flow pathways stained by a 10-min pulse of dye after 2 hours of ponded infiltration. White circles show location of small core samples, two in dyed zones and two in undyed zones.

Results

Infiltration rates at the end of the 2-hour ponded infiltration averaged 1.6 inches per hour in tilled plots and 2.2 inches per hour in untilled plots. These are normal rates for these methods and tillage treatments on this soil (Wuest 2005, Wuest et al. 2006).

Analysis of the iodine-tracer samples collected in untilled plots resulted in 1.23 percent total soil carbon in preferential flow zones versus 1.20 percent in bulk soil. The difference was not statistically significant ($P > F$, 0.1898).

Root mass differed only between tillage treatments ($P > F$, 0.0003). There were more roots in tilled plots (0.085 g/sample) than untilled plots (0.027 g). It should be noted, however, that while samples were balanced for dyed and undyed zones by taking sample cores from both in each cylinder cross-section, it was sometimes necessary to decrease the depth of sampling to find dyed zones in tilled soil. This probably influenced the root comparison between tilled and untilled soil, so the greater root mass measured in tilled soil should be considered a tentative result.

Within both tilled and untilled soils, preferential flow zones had lower bulk density than non-preferential flow zones ($P > F$, 0.0106; Fig. 2). On average, however, tilled plots had lower bulk density than untilled plots ($P > F$, 0.0001). There was no interaction between zones and tillage.

Samples taken from preferential flow zones had greater aggregation (Fig. 3) and, therefore, less material < 53 µm ($P > F$, 0.0415), less retained on top of the 53-µm sieve ($P > F$, 0.0445), and more retained on the 1-mm (= 1,000 µm) sieve ($P > F$, 0.0216). Compared to untilled soil, tilled soil had a lower proportion of water-stable aggregates. More soil passed through the 53-µm sieve ($P > F$, 0.0001), and less material was retained on the 250-µm sieve ($P > F$, 0.0115) compared to untilled soil. There were no statistically significant interactions at $P = 0.05$, although it can be seen in Figure 3 that the tilled, bulk soil had a major influence on the statistically significant factors.

As might be expected, preferential flow zones had greater water content (Fig. 2). This was statistically significant ($P > F$, 0.0009) when calculated as gravimetric water content. Tilled soil had greater water content both as gravimetric ($P > F$, 0.0001) and volumetric ($P > F$, 0.0003) water contents. There was no interaction between zone and tillage.

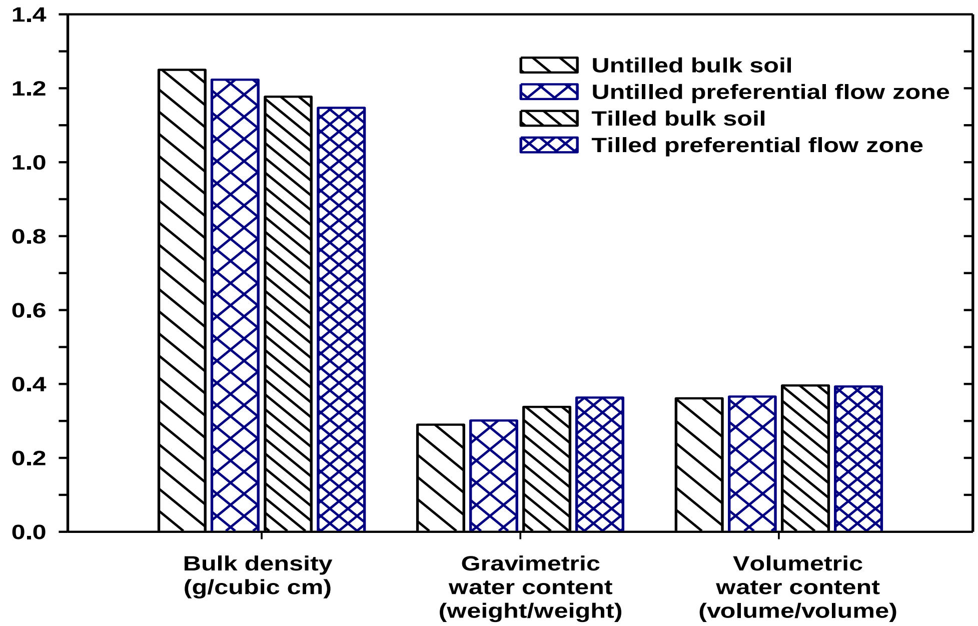

Figure 2. Soil bulk density, gravimetric, and volumetric water content of soil samples taken from preferential flow zones and undyed bulk soil of tilled and untilled plots. The difference between tilled and untilled plots is statistically significant for all three factors. The difference between preferential flow zones and bulk soil is statistically significant for bulk density and gravimetric water content.

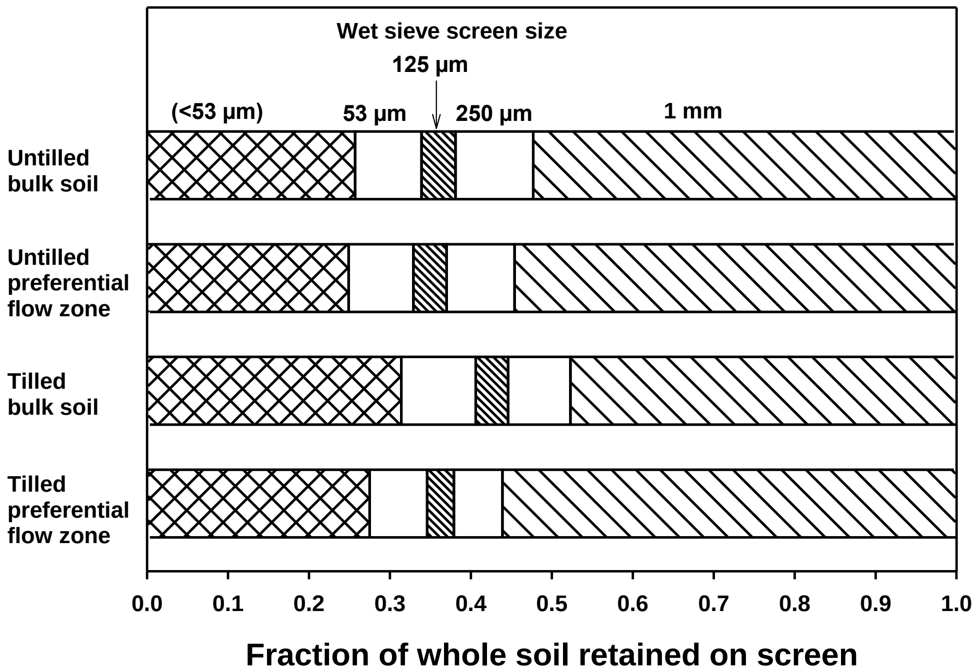

Figure 3. Proportion of water-stable aggregates in each of five size classes. Tilled and untilled plots are statistically different for < 53 µm and 250 µm. The difference between bulk soil and preferential flow zones are statistically significant for < 53 µm, 53 µm, and 1 mm.

Discussion

Use of dye to mark preferential flow paths for short periods of time created clearly demarcated dyed and undyed areas of soil in cylinder cross-sections as shown in color reproduction of Figure 1. In our experience, if the cylinders were left unexcavated for 18 hours after removing the dye solution from the soil surface, the dye staining patterns still appear distinct and not noticeably different than when excavated immediately.

Bulk soil was identified as any soil that did not contain dye. There is no reason to believe that the absence of dye indicates an incapacity for high rates of water flow. In other words, dye is proof of high velocity water flow, but lack of dye might only indicate that soil was not sufficently connected to high flow soil both above and below to be part of a preferential flow path. This connectivity issue indicates that statistically significant differences are probably robust.

As discussed in the introduction, one possible cause for increased water infiltration rates over time after tillage ceases would be an increase in preferential flow capacity of individual flow zones. If roots tend to grow into previous root channels, they might provide positive feedback for increased water availability, aeration, nutrient turnover, and soil aggregation. We also anticipated that root mass might be greater in preferential flow zones because dye has been seen in association with roots, and roots can produce vertical pathways for water infiltration (Gish and Jury 1983). In this dataset, however, root mass was not greater in preferential flow zones, and carbon differences were not significant. Aggregation was greater in preferential flow zones, but there was more of a difference in tilled soil than in untilled soil. This indicates that preferential flow zones were not developing better aggregation over time in untilled soil. These results do not support the hypothesis that there is increasing zone development over time after tillage stops.

The difference in soil density between preferential flow zones and bulk soil was similar for tilled and untilled plots. Infiltration rate was greater in untilled soil even though bulk density in flow zones of untilled soil was greater than either zone in tilled soil (Fig. 2). Greater bulk density in untilled soil often accompanies greater hydraulic conductivity, which is attributed to fewer but better connected pores (Strudley et al. 2008). Our personal observation, based on hundreds of cylinder cross-sections from this and other experiments, is that the dyed flow zones in untilled soil comprise a greater proportion of the soil, are more uniformly distributed, and create deeper dye penetration than in tilled soil (Wuest 2005). Greater gravimetric and volu-metric water contents in tilled soil (Fig. 2) might indicate a greater resistance to water flow below the soil surface. This agrees with our observation that tilled soil remains wetter than untilled soil when infiltration cylinders are left to drain *in situ* overnight. So while the difference between bulk soil and preferential flow zones was not greater in soil untilled for 7 years, the lower water content (better drainage) of untilled soil indicates the flow zones may be more effective as well as more numerous.

Contrary to the original hypothesis, it is possible that preferential flow zones develop in-creased bulk density and smaller differences in aggregate stability over time, and that the in-crease in water infiltration rates is a result of more of the potential flow zones being sufficiently connected to the surface. If untilled soils develop a surface soil with greater resistance to slaking and sealing, the increased connectivity to greater numbers of potential flow zones might increase infiltration rates even if overall bulk density increases with time after tillage stops.

Conclusions

Dyed soil zones known to be conducting water at high velocity differed from bulk soil in proportion of stable aggregates and in soil bulk density. Surprisingly, bulk density in preferential flow zones of the untilled soil were greater than either preferential or bulk soil of the tilled soil despite the untilled soil having greater total water conductivity. This may mean that the existence of an active preferential flow path is more dependent on its connection to a surface water source than on its own water transport characteristics. Untilled soils often accumulate surface organic matter and therefore have stronger surface soil aggregation, which may lead to less restriction of water flow to potential preferential flow zones below the surface.

These results focus attention on the top inch of the soil surface. If this shallow zone is controlling water infiltration and preferential flow, then its careful characterization may be as important to accurate modeling and soil management as characterization of soil at lower depths.

Note: More details on this research are published in Vadose Zone Journal, 2009.

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Long-term Experiments at CBARC-Moro and Center of Sustainability-Heppner, 2007-2008

Stephen Machado, Larry Pritchett, Erling Jacobsen, Steve Petrie, Dick Smiley, Dan Ball, Don Wysocki, Stewart Wuest, Hero Gollany, and William Jepsen

Abstract

The main focus of this experiment is to develop profitable and sustainable direct seeding cropping systems for north-central Oregon. Specific objectives are to increase residue cover; increase soil organic matter (OM); increase available soil moisture; reduce wind and water erosion; reduce soil water evaporation; and sustain soil productivity. The experiment, now in the fifth year, is being conducted at Moro and Heppner. Two more crop-years are required for all crop rotations to complete a full cycle. The experiment compares the traditional wheat-fallow system with direct-seeded (DS) wheat-chemical fallow, DS annual winter wheat, DS spring wheat, DS spring barley, DS winter wheat-winter pea rotation, and DS winter wheat-spring barley-chemical fallow rotation. This report covers the 2007-2008 crop-year results and summarizes results from the last 4 years. At Moro, DS annual spring barley, with low root-lesion nematode (*Pratylenchus* spp.) incidences, produced the highest yields. Direct-seeded annual spring wheat produced the lowest yields for the first time in 4 years, probably due to a high incidence of root-lesion nematodes. Direct-seeded annual winter wheat produced yields comparable to DS annual spring barley. Direct-seeded winter wheat after chemical fallow in the 3-year rotation with spring barley, also with low root-lesion nematode incidences, produced the highest yields although this was not significantly different from DS winter wheat following chemical fallow and winter wheat following conventional tillage fallow. Based on the 4-year average (2004-2005 to 2007-2008 crop-years), winter wheat following fallow in a 3-year rotation with spring barley produced the highest yields, although these yields were not significantly different from yields of wheat after conventional tillage fallow. The high wheat yield obtained from the 3-year rotation is partly attributed to low levels of root-lesion nematode incidences and low weed infestation. Yields from annual crops were strongly influenced by annual precipitation. Direct-seeded annual spring barley produced the highest yield, followed by winter wheat after winter pea. Direct-seeded annual winter wheat produced the lowest yields over the 4 crop-years. This was probably due to a combination of high downy brome (*Bromus tectorum*) infestation, observed in the first 3 years, and high incidences of root-lesion nematodes, but not due to a shortage of water. Grain yields of all crops were negatively associated with root-lesion nematode incidences. At Heppner during the 2007-2008 season, winter wheat after chemical and conventional tillage fallow produced higher yields than annual crops. The 4-year (2004-2005 to 2007-2008) average followed the same trend. However, on an annualized yield basis, DS annual spring barley produced the highest grain yields followed by DS annual winter wheat. Annualized yields of winter wheat following fallow (conventional or chemical) were similar to yields obtained from DS annual spring wheat and hard red spring wheat.

Keywords: direct seeded, fallow, long-term experiment, root-lesion nematode, wheat.

Introduction

The conventional tillage (CT) winter wheat-summer fallow rotation reduces soil organic carbon, exacerbates soil erosion, and is not biologically sustainable (Rasmussen and Parton 1994). 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 (Hall 1955, 1960, 1963. But with the advent of new varieties and agronomic practices such as direct seeding, long-term research is needed to evaluate benefits and risks of annual cropping, potential alternate crops, and alternative rotations. The main focus of this work is to establish and maintain long-term experiments that compare the conventional wheat-fallow system with alternate cropping systems and crop management practices such as direct seeding that reduce wind and water erosion. Specific objectives include developing systems that increase residue cover; increase soil organic matter and biological activity; increase water infiltration and available soil moisture; reduce wind and water erosion; reduce soil water evaporation; reduce pests; sustain soil and crop productivity; evaluate the variable costs and crop value of the cropping systems under evaluation; and extend the results to growers. The research is targeted for Agronomic Zones 4 and 5 in north-central Oregon.

Methods and Materials

CBARC, Sherman Station, Moro

The experiment was established on a 28-acre site at the Columbia Basin Agricultural Research Center (CBARC) in Moro in the fall of 2003. The experiment has completed 4 crop-years so far (2004-2005 through 2007-2008). The soil is a Walla Walla silt loam (coarse, silty, mixed, mesic Typic Haploxeroll) and more than 4 ft deep. The Center receives an average of 11.5 inches of annual precipitation. Rainfall and soil at the station is 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, for a minimum total experimental area of 13.88 acres. Agronomic practices, such as planting date, planting rate, and fertilizer, herbicide, seed-treatment fungicide, and insecticide application, are based on the optimum management for each rotation and crop. Direct-seeding is conducted using the Fabro® drill.

Field operations

During the 2007-2008 crop-year, Clearfield® winter wheat cultivar (ORCF 101) was used in all treatments with winter wheat to control grassy weeds, particularly downy brome (*Bromus tectorum*) whose population was high in annual winter wheat treatments. ORCF 101 in rotation 1 was seeded at 18 seeds/ft^2 on October 10, 2007 using an HZ drill. ORCF 101 in rotation 2 and 6 was seeded on November 2, 2007 and in rotation 3 and 7 on November 15, 2007. Spring pea for rotation 7 was direct-seeded at the rate of 7 peas/ft^2 (120 lbs/acre) on February 26, 2008.

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

Rotation	Description†
1	Winter wheat-conventional fallow (CT)
2	Winter wheat-chem. fallow (DS)
3	Annual winter wheat (DS)
4	Annual spring wheat (DS)
5	Annual spring barley (DS)
6	Winter wheat-spring cereal (barley)-chem. fallow (DS)
7	Winter wheat-winter pea (DS)
8	Flex crop-(crop to be chosen each year based on soil moisture and market price)

†CT = conventional tillage; DS = direct seeded.

Granular inoculant was applied with the seed at the rate of 57 g/1,000 ft. Camelina for rotation 8A was seeded on April 4, 2008. Spring (yellow) pea in rotation 8B was seeded at 120 lbs/acre on April 11, 2008. 'Haxby' spring barley in rotation 5 and 6 was direct-seeded at 20 seeds/ft^2 on April 5, 2008 and 'Louise' spring wheat in rotation 4 and 8a (flex) was seeded at 22 seeds/ft^2 on April 4, 2007. Each phase of each rotation is present each year. Fertilizer N rates from 10 to 50 lbs/acre were applied to plots of different rotations to bring up the N levels to 80 lbs N/acre. Data on plant stand, phenology, weeds, and diseases were collected. Herbicide application history is shown in Table 2. Weed plant counts were taken in March and May of each year.

Diseases were monitored by sampling three plots (replicates) of early-planted winter wheat (rotation 1) on April 14, 2008. All other plots planted to cereals and broadleaf crops were sampled on June 11. Plant samples consisted of 20 to 40 plants plus intact roots collected over the length of each plot; soil was washed from the roots, and each root system was rated for incidence (percent plants infected) and severity (qualitative rating scale) of diseases such as Fusarium foot rot, take-all, Rhizoctonia root rot, and Pythium root rot. We also examined plants for the presence or level of damage by other diseases and insect pests but none were observed. Soil samples (about 20 cores per plot; 1 inch diameter and 12 inch depth) were collected on April 14 and sent to Western Laboratories (Parma, Idaho) for quantification of plant-parasitic nematode genera. At maturity, plots were harvested using a commercial combine with an 18-ft header. The 18-ft swath was taken in the center of the 48-ft-wide plot. Grain was weighed using a weigh-wagon to determine yield per treatment.

Table 2. Herbicide applications in the 2007-2008 crop-year at the Sherman Station, Moro, Oregon.

Rotation	Herbicide	Date
7	RT-3 + Quest + NIS (24 oz + 5 pts + 32 oz)	2/22/08
1,2,4,5,6,8	RT-3 + Quest + NIS (24 oz + 5 pts + 32 oz)	3/19/08
1,2	Beyond + Turret + soln 32 (5 oz + 0.25% + 1.25%)	4/13/08
2,3,7	Beyond + Turret + soln 32 (5 oz + 0.25% + 1.25%)	4/24/08
6	Harmony X + 2,4-Da + NIS (0.6 oz + 16 oz + 0.25%)	4/29/08

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 at these depths. 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 in Heppner, Oregon. In the past 4 years (2004-2005 to 2007-2008) cropping systems that are similar to the proposed cropping systems at the Sherman Station at Moro have been evaluated at this site (Table 3). The Center of Sustainability (COS) site receives, on average, similar crop year precipitation to Moro (11 inches), but it is shallower (2 ft deep) than the Moro site (over 4 ft deep). This makes it possible to determine the influence of soil depth on the alternate cropping systems. 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 valid statistical methods for unreplicated studies (Perrett and Higgins 2006).

Table 3. Cropping and tillage systems under evaluation at the Center of Sustainability study at Bill Jepsen's farm in Heppner, Oregon.

Treatment/Rotation	Description†
1	Conventional winter wheat/conventional fallow (CT)
2	Winter wheat/chemical fallow (DS)
3	Annual spring barley (DS)
4	Annual spring wheat (DS)
5	Annual spring hard red spring wheat (DNS) (DS)
6	Annual winter wheat (DS)
7	Spring barley/mustard/spring wheat (DS)
8	Winter wheat/mustard/chemical fallow (DS)
9a,b	Flex crop

†CT = conventional tillage; DS = direct seeded; DNS = dark northern spring wheat

Results and Discussion

CBARC, Sherman Station, Moro

Precipitation

Total precipitation during the 2007-2008 crop-year was the second lowest (8.4 inches) in 4 years (Fig.1). Spring precipitation was also lowest of the four seasons. Temperatures were lower than normal from January to April and higher than normal in May and June during the reproductive phases of the crops. The combination of low precipitation and unfavorable temperatures during the reproductive phases of the wheat was probably the cause of the reduced yields obtained from all treatments in this season.

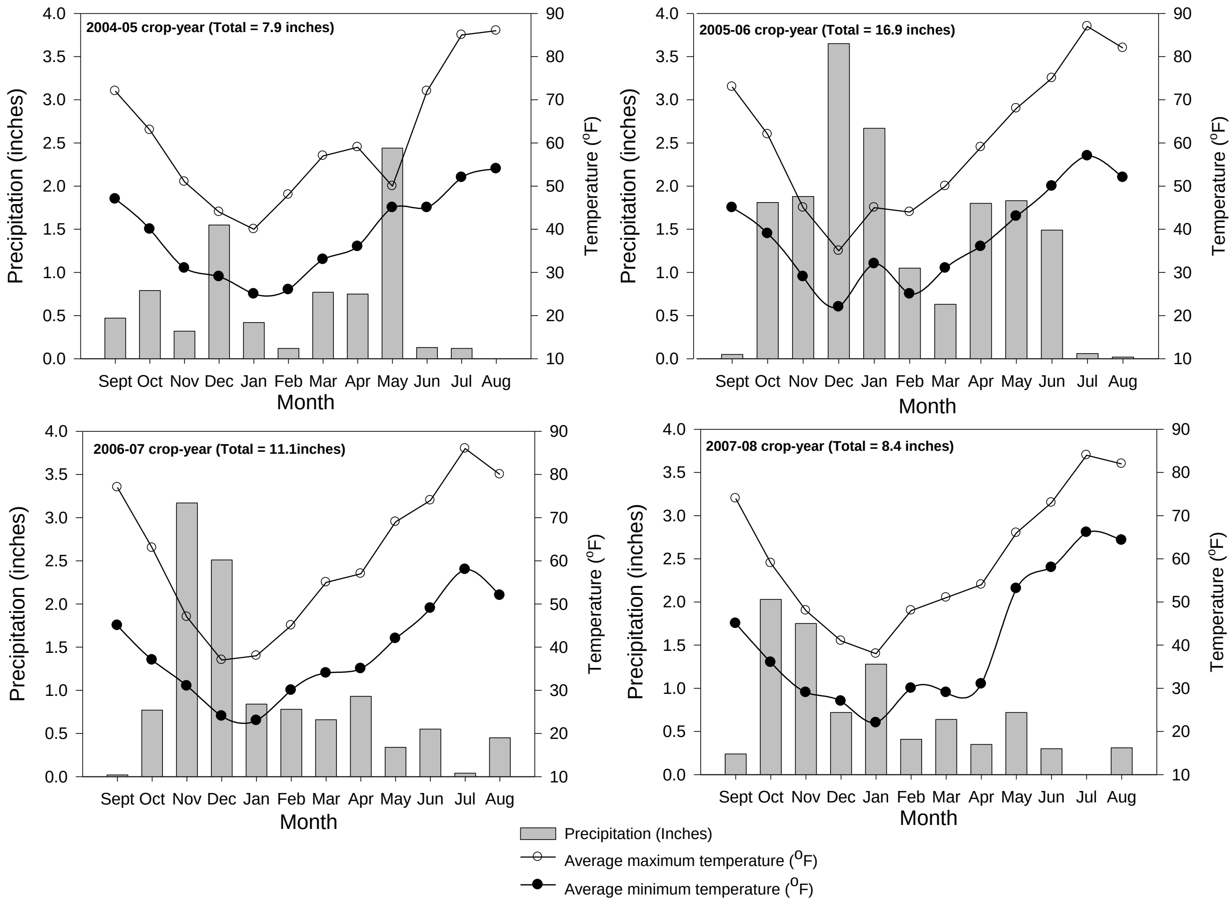

Figure 1. Precipitation and average maximum temperatures at the Columbia Basin Agricultural Research Center Sherman Station, Moro, Oregon, long-term cropping systems experiment from 2004-2005 to 2007-2008 crop years.

Soil water measurements

Soil moisture (average of whole 40-inch profile) for each treatment in 2008 is shown in Figure 2. As expected, fallow treatments contained the most moisture throughout the season. The amount of water stored in the fallow treatments decreased with time from spring to fall. The chemical fallow treatment (Table 1, rotation 6) had the lowest soil moisture from the start to the end of the measurements. Moisture in plots with crops decreased as the season progressed due to increased evapotranspiration. Soil moisture in plots grown to winter wheat after fallow decreased the most. Moisture in plots under annual winter wheat was lower compared to 2006 and 2007 (Figs. 3 and 4) suggesting that this year's crop used more water than previous years. In 2006 and 2007, moisture in plots grown to annual winter wheat remained higher than other cropped plots throughout the season, indicating that wheat under this treatment was unable to use the available moisture.

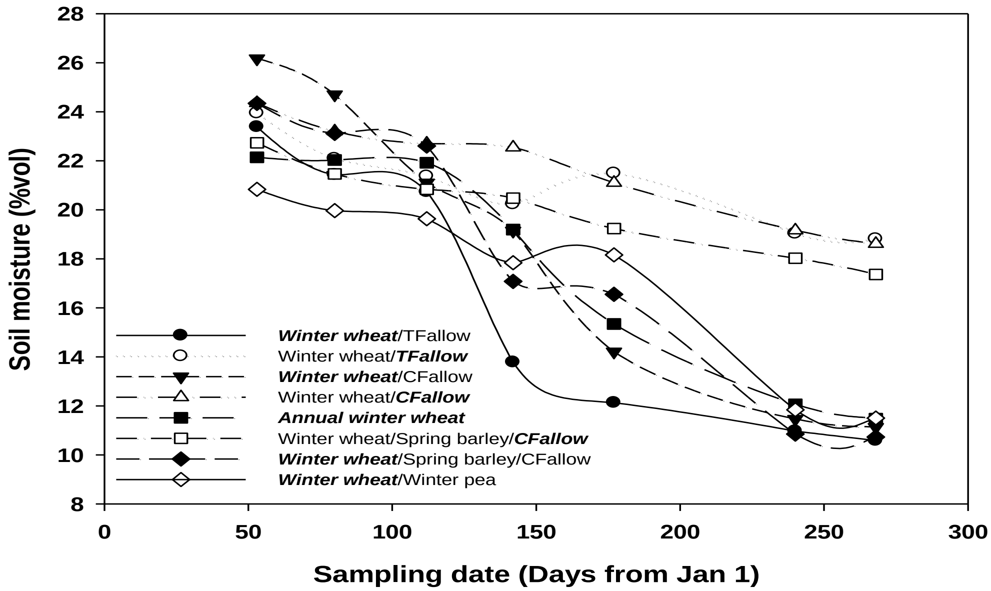

Figure 2. Average soil water content under all rotations in the 0- to 40-inch depth profile in 2008, at Columbia Basin Agricultural Research Center, Moro, Oregon. Data shown are for crop/treatment in boldface and italics of a rotation.

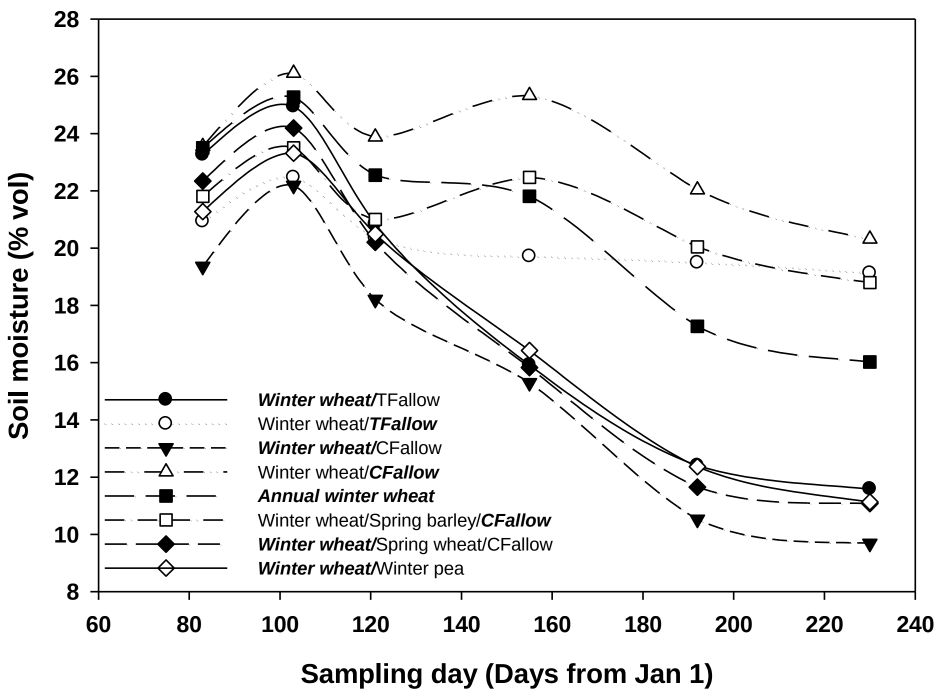

Figure 3. Average soil water content under all rotations in the 0- to 40-inch depth profile from March to August, 2006, at Columbia Basin Agricultural Research Center, Moro, Oregon. Data shown are for crop/treatment in boldface and italics of a rotation.

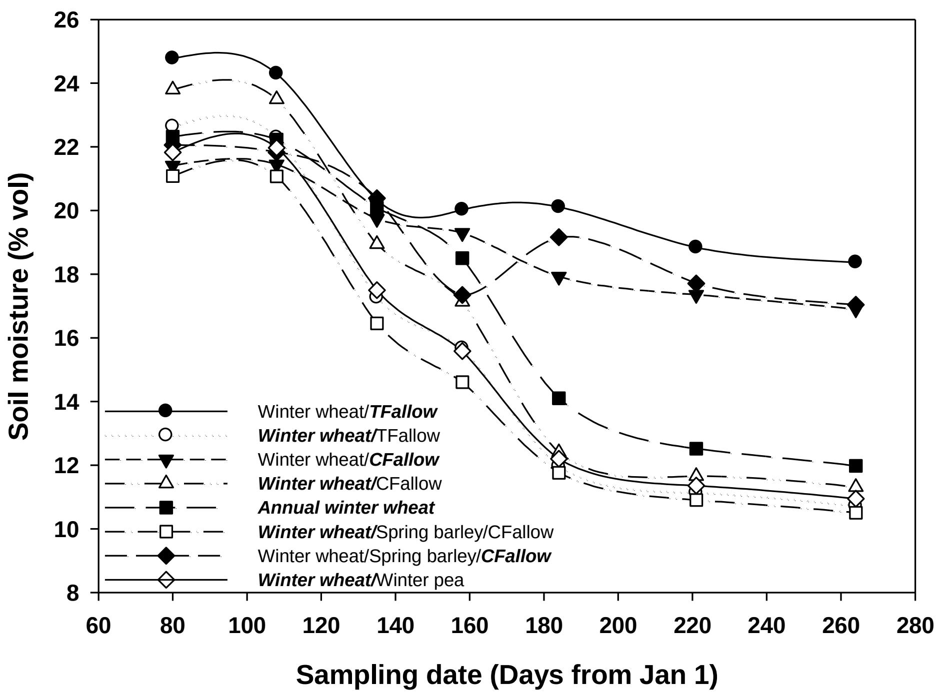

Figure 4. Average soil water content under all rotations in the 0- to 40-inch depth profile from March to September, 2007, at Columbia Basin Agricultural Research Center, Moro, Oregon. Data shown are for crop/treatment in boldface and italics of a rotation.

Weeds

The weeds team evaluated downy brome and broadleaf weed control in the cropping systems under study. We found that downy brome populations were substantially reduced in recrop direct-seeded winter wheat in 2008 (Table 4). During this year Clearfield wheat (ORCF 101) was grown and sprayed with imazamox (Beyond®) herbicide. Despite planting of a Clearfield variety and treatment with Beyond, downy brome infestations were still present in winter wheat plots (Table 4) but infestation levels were moderate. In plots of annual winter wheat, however, downy brome populations were reduced from 41 plants/m^2 in 2007 to 6 plants/m^2 in 2008. Prickly lettuce (*Lactuca serriola*) and prostrate knotweed (*Polygonum aviculare*) densities were high in winter wheat grown in rotation with pea. This is likely due to less effective and late-season control of these broadleaf weed species in the previous winter pea crop. Winter pea lacks effective broadleaf herbicide treatment options. Early-season weed counts did not indicate high levels of weed infestation from these species. Rattail fescue (*Vulpia myuros*) was also evident in direct-seeded, annual winter wheat. This is a weed problem seen in commercial, direct-seeded winter wheat.

Table 4. Downy brome populations in different cropping systems after herbicide treatment, Moro, Oregon, 2004-2008.

	Treatment[1]	Downy brome 5/5/04	5/3/05	5/19/06[2]	5/17/07	5/10/08
		---------------no./m²---------------				
1	WW – conven	5	2	6	0	14
2	Fallow-conven	0	1	0	2	0
3	WW – DS	4	2	12	41	6
4	Fallow-chem	0	2	0	3	0
5	WW – DS	8	11	20	4	2
6	SW – DS	0	0	0	2	0
7	SB – DS	0	0	2	0	0
8	WW – DS	8	0	0	0	0
9	SB – DS	0	0	0	1	0
10	Fallow-chem	0	5	0	3	4
11	WW – DS	8	0	8	2	3
12	WP – DS	2	1	0	0	0
13[3]	SW	0	0	0	1	0
14[4]	SW	0	0	0	1	0
	LSD (0.05)	7	4	8	9	4

[1]WW = winter wheat, SW = spring wheat, SB = spring barley, WP = winter pea, DS = direct seeded.
[2] Treatments 1, 3, 5, 9 and 11 did not receive a grass herbicide before May 19, 2006.
[3] Flex crop in 2004 was spring wheat, in 2005 it was spring barley, and in 2006 it was mustard.
[4] Treatment 14 was plowed up in 2006.

Diseases

Fungal diseases of cereal crops

The incidence of subcrown internode lesions on winter wheat, caused by Fusarium crown rot, was highest where winter wheat was sown into the 2-year rotations of winter wheat and either summer fallow or winter pea (Table 5). The incidence of sub-crown internode lesions in winter wheat-summer fallow rotations was higher when the wheat was planted early into cultivated fallow compared to wheat planted later into chemical fallow. Fusarium also caused extensive lesion development on subcrown internodes of wheat and barley planted during the spring. There were no statistical differences among treatments for the incidence and severity of Rhizoctonia root rot and take-all.

Fungal diseases of broadleaf crop

There were no statistical differences among disease ratings for the three broadleaf crops. High proportions of the cotyledons exhibited a black-colored root rot (Table 6) but the severity of disease was relatively low. Symptoms of infection by *Fusarium* and *Rhizoctonia* were present on most tap roots but disease severity was again low to moderate. Vascular browning, typical of Fusarium wilt, was present but also at a low level of severity. Nubbing or pruning of branch roots, typically caused by species of *Rhizoctonia*, *Pythium*, and/or *Pratylenchus*, was prevalent but not severe. No attempt was made to associate disease symptoms with specific pathogens or pathogen complexes.

Root-lesion nematodes

The root-lesion nematode (*Pratylenchus neglectus*) was the primary plant-parasitic nematode species detected. Other nematode genera and species occurred in a few plots but were always at very low populations and there was no pattern of association with a crop rotation or crop management variable. When samples were collected during early spring the winter crops were well established and spring crops were recently planted.

Root-lesion nematode populations differed significantly among treatments during 2008 (Table 7). Populations of root-lesion nematodes were lowest in annual spring barley, and were highest in the winter wheat-winter pea rotation and in annual spring and winter wheat. Populations in the winter wheat-summer fallow rotations were statistically equal in each phase (planted vs. fallow) of the rotation.

Patterns in root-lesion nematode populations over rotational and management sequences were apparent when rotations were analyzed over 5 years (Table 7). Rotations with lowest populations include annual spring barley and 2 of the 3 3-year rotations of winter wheat, spring barley, and chemical fallow. Annual winter wheat and the winter wheat-winter pea rotation had the highest populations of root-lesion nematodes. These patterns are also clear when the 5-year data set is examined by grouping data based on the previous crop or management (Table 8). Populations were highest following crops of winter wheat, winter pea, and spring mustard, and lowest following spring barley and chemical fallow. Root-lesion nematode populations were negatively correlated with grain yield of all crops (Fig. 5.)

Table 5. Fungal diseases of wheat and barley roots in the long-term experiment at the Sherman Station, Moro, Oregon, 2008.

	2008 trt[1]	1	3	5	6	7	8	10	11		
	Rotation:	1A	2A	3	4	5	6A	6C	7A		
	2008	Conv WW	Dir Seed WW	Dir Seed WW	Dir Seed SW	Dir Seed SB	Dir Seed SB	Dir Seed WW	Dir Seed WW		
	2007	Conv Fallow	Chem Fallow	Dir Seed WW	Dir Seed SW	Dir Seed SB	Dir Seed WW	Chem Fallow	Dir Seed WP		
	2006	Conv WW	Dir Seed WW	Dir Seed WW	Dir Seed SW	Dir Seed SB	Chem Fallow	Dir Seed SB	Dir Seed WW		
	2005	Conv Fallow	Chem Fallow	Dir Seed WW	Dir Seed SW	Dir Seed SB	Dir Seed SB	Dir Seed WW	Dir Seed WP		
	2004	Conv WW	Dir Seed WW	Dir Seed WW	Dir Seed SW	Dir Seed SB	Dir Seed WW	Chem Fallow	Dir Seed WW	lsd $_{0.05}$	$P > F$
Parameter[2]											
SCI	% plants	96	51	26	71	84	77	18	51	20.3	<0.0001
	severity	2.6	1.1	0.9	1.4	2.1	2.1	1.0	1.4	1.0	0.0256
Infected crowns	% plants	0	0	0	3	7	13	0	4	ns	0.6740
SR - RRR	% plants	0	10	9	11	10	2	7	0	ns	0.7774
	severity	0	0.3	0.3	0.7	0.3	0.3	0.3	0	ns	0.6586
SR - TA	% plants	23	27	8	37	48	44	28	31	ns	0.5741
	severity	1.9	1.0	0.7	1.3	1.9	1.6	0.9	1.1	ns	0.4922
SR - FCR	% plants	96	87	91	67	81	87	62	100	ns	0.5516
	severity	3.1	2.1	2.6	1.9	2.2	2.3	1.8	3.0	ns	0.4355
CR - RRR	% plants	2	10	10	8	5	10	10	12	ns	0.8105
	severity	0.3	0.8	1.0	0.7	0.7	0.7	0.7	1.2	ns	0.7401
CR - TA	% plants	38	10	7	17	38	17	28	10	ns	0.3948
	severity	1.3	0.4	0.3	1.3	0.9	0.4	1.2	1.3	ns	0.1445
CR - FCR	% plants	93	65	62	63	68	57	82	73	ns	0.1538
	severity	1.8	1.3	1.2	1.4	1.6	1.8	1.6	1.4	ns	0.4528
PRR or RLN?	% plants	8	3	5	0	0	5	2	3	ns	0.8430

[1]trt = treatment; WW = winter wheat, SW = spring wheat, SB = spring barley, WP = winter pea.
[2] SCI = lesions on sub-crown internodes, SR = seminal roots, CR = crown roots, RRR = Rhizoctonia root rot, TA = take-all, FCR = Fusarium crown rot, PRR = Pythium root rot, RLN = root-lesion nematode, “% plants” = percent plants exhibiting symptom described, “severity” = disease severity rating scale (0-4; 4 = most severe), lsd – least significant difference; ns = not significantly different.

Table 6. Diseases of broadleaf crop cotyledons and roots in the long-term experiment at the Sherman Station, Moro, Oregon, 2008.

Treatment		12	13	14
Rotation		7B	8A	8B
Current crop		Winter pea	Spring pea	Camelina
Previous crop		Winter wheat	Spring wheat	Winter wheat
Parameter[1]				
Black cotyledon	% plants	88.3	60.0	69.7
	severity	1.8	1.4	1.2
Root rot lesions on tap root	% plants	100	87.5	81.7
(Rhizoctonia/Pythium complex)	severity	1.9	1.2	1.3
Vascular browning	% plants	43.3	35.0	38.7
(Fusarium wilt??)	severity	1.0	1.0	1.0
Branch roots "nubbed" off	% plants	65.0	52.5	49.3
	severity	1.4	1.1	1.0

[1] % plants = percent plants exhibiting symptom described, severity = disease severity rating scale (0-4; 4 = most severe).

Table 7. Density of root-lesion nematodes (*Pratylenchus neglectus*/kg of soil) in the upper soil profile of the long-term experiment at the Sherman Station, Moro, Oregon, 2008.

Rotation	Crop or management						*P. neglectus*/kg of soil [1]					
	2008	*2007*	*2006*	*2005*	*2004*	*2003*	*5-yr mean 2004-2008*	*2008*	*2007*	*2006*	*2005*	*2004*
1A	WW [3]	CoF [2]	WW [3]	CoF	WW [3]	ChF	2,321 a	3,276 ab	3,253 ab	938 abc	4,920 a	1,369 a
1B	CoF	WW [3]	CoF	WW	CoF	ChF	969 ab	2,440 ab	684 cd	984 abc	861 a	604 a
2A	WW [3]	ChF	WW [3]	ChF	WW [3]	ChF	2,195 ab	4,706 ab	2,932 ab	1,082 abc	897 a	3,800 a
2B	ChF	WW [3]	ChF	WW [3]	ChF	ChF	633 b	3,663 ab	732 cd	203 d	413 a	422 a
3	annual WW [3]					ChF	2,653 a	5,877 a	4,464 a	3,126 a	2,796 a	573 a
4	annual SW					ChF	1,900 ab	8,641 a	3,617 ab	1,129 abc	2,832 a	247 a
5	annual SB					ChF	626 b	413 b	691 cd	470 bcd	2,409 a	297 a
6A	SB	WW [3, 4]	ChF	SB	WW [3]	ChF	806 ab	931 ab	371 d	885 abcd	1,886 a	591 a
6B	ChF	SB	WW [3]	ChF	SB	ChF	810 ab	1,886 ab	2,160 abc	342 cd	353 a	709 a
6C	WW [3]	ChF	SB	WW	ChF	ChF	1,481 ab	1,199 ab	1,668 abc	1,632 ab	1,873 a	1,166 a
7A	WW [3]	WP [3]	WW [3]	WP [3]	WW [3]	ChF	2,449 a	11,052 a	5,401 a	1,187 abc	1,483 a	838 a
7B	WP [3]	WW [3]	WP [3]	WW	WP [3]	ChF	1,665 ab	7,326 a	2,268 abc	1,691 ab	1,356 a	335 a
8A	SP	SW	SM	SW	SB	ChF	1,760 ab	7,708 a	1,839 abc	670 bcd	2,322 a	767 a
8B	camelina	WW [3]	SM	SB	SW	ChF	1,265 ab	2,803 ab	1,100 bcd	1,542 ab	1,482 a	458 a
$P > F$ [5]							0.0002**	0.006**	0.005**	0.072	0.762	0.313
CV (%)							14.3	11.3	10.4	12.5	21.2	16.9

[1]Sampling was from the top 6 inches in spring 2004 and on March 7, 2005, and from the top 12-inches on April 4, 2006, April 2, 2007, and April 14, 2008.

[2]CoF = conventional fallow, ChF = chemical fallow

[3]Treatments that were planted during the fall and were therefore "in-crop" for 5 months prior to sampling. Sampling of all other plots was performed immediately after spring crops were planted, including samplings of summer fallow treatments. All except treatments 1 and 2 are direct seeded, e.g., no-till.

[4]Winter wheat plots in rotation 6A were very dry and compact on April 2, 2007. It was impossible to collect manual core samples to the same depth as for other plots. Low numbers of root-lesion nematodes may be somewhat biased by the slightly shallower sampling depth in those three plots.

[5]Data are from back-transformed means of the ln (x+1) transformation used for ANOVA.

** = significant at the 0.01 probability level

Table 8. Density of root-lesion nematodes (*Pratylenchus* spp./kg of soil, RLN) during early spring following specific crops or management practices over a 5-year period (2004-2008) in the long-term experiment at the Sherman Station, Moro, Oregon, 2008.

Previous crop or management	RLN[1]	n[2]
Winter wheat	2,276 a	63
Mustard	1,839 a	3
Spring wheat	1,035 ab	65
Winter pea	2,520 a	12
Spring barley	967 b	27
Conventional fallow	1,160 ab	12
Chemical fallow	971 b	30
P > F[3]	0.0020**	
CV (%)	17.1	

[1]Calculated as the back-transformed mean for samples from the top 6 inches of soil on March 7, 2005, and from the top 12 inches on April 4, 2006, April 2, 2007, and April 14, 2008.
[2]Number of plots for specific treatments over the 5-year history of the experiment; crop years 2004-2008.
[3]Data are from back-transformed means of the ln (x+1) transformation used for ANOVA.
** = significant at the 0.01 probability level

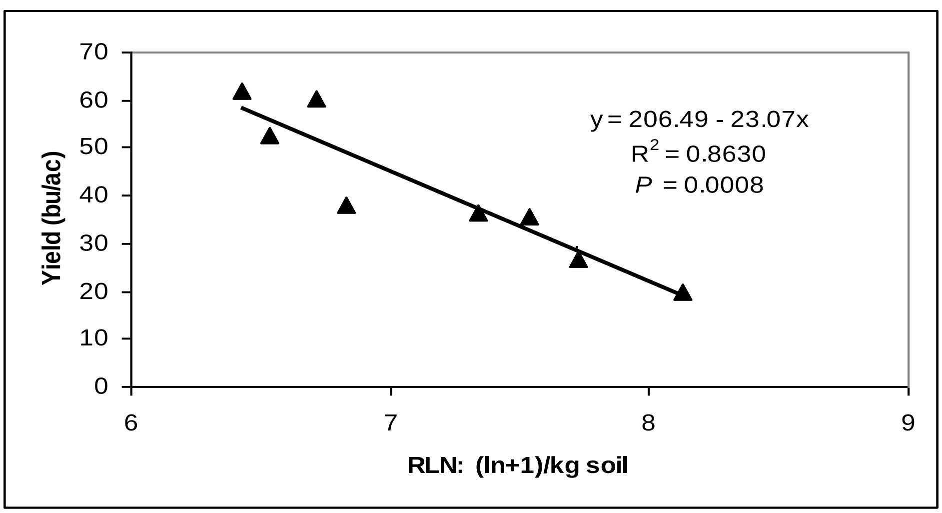

Figure 5. Relationship between root-lesion nematode populations (RLN; expressed as the log transformed number/kg of soil) and yields for winter wheat, spring wheat, and spring barley averaged over 3 years (crop years 2005-2007) as shown for the ‘5-yr average’ in Table 8.

Grain yield of winter and spring crops under different cropping systems

The 2007-2008 crop-year was the fifth cropping season of this experiment but fourth season in terms of meaningful results. The first year (2003-2004) was a set-up year. Treatments with 2-year rotations have completed a full cycle. Two more years are required to complete a full cycle for 3-year-rotation treatment. Grain yields of winter wheat, spring wheat, spring barley, and winter pea obtained in the 2007-2008 crop year are shown in Table 9. Of the four years, this crop-year had the second lowest precipitation (8.4 inches), which resulted in reduced yields of annual crops. Yields of winter wheat after either conventional or chemical fallow were also significantly reduced when compared to 2006-2007 because of low spring precipitation (Fig. 1). Annual spring barley produced the highest yield compared to winter and spring wheat under annual cropping. This was partly due to low density of root-lesion nematodes in annual spring barley compared to winter wheat where the density was highest. However, annual spring barley yields were not significantly different from yields produced by spring barley following winter wheat in the 3-year rotation (rotation 6). Highest yields were produced by winter wheat following either conventional or chemical fallow and annual spring wheat produced the lowest yields. Results from the 2006-2007 crop-year indicate that soil moisture was not limiting, leading us to the conclusion that other factors influenced the yield of annual winter wheat. Downy brome populations were highest in this treatment (Table 4) indicating a problem with grassy weed control in this treatment. Furthermore, there were high incidences of Fusarium crown rot lesions in this treatment that could have reduced yields.

Based on the 4-year average (2004-2005 through 2007-2008 crop-years) winter wheat following fallow in a 3-year rotation with spring barley produced the highest yields although these yields were not significantly different from yields of wheat after conventional tillage fallow (Table 9). The high wheat yield obtained from the 3-year rotation is partly attributed to low levels of root-lesion nematode incidences and low weed infestation. Yield from the 3-year rotation was significantly higher than yield of winter wheat following chemical fallow. Yields from annual crops were strongly influenced by annual precipitation (Table 9). Annual spring barley, with the lowest root-lesion nematode incidences (Tables 7 and 8), produced the highest yield followed by winter wheat after winter pea, with the lowest root-lesion nematode incidences (Tables 7 and 8). Annual winter wheat produced the lowest yields over the 4 crop-years. This was probably due to a combination of high downy brome (*Bromus tectorum*) infestation that was observed in the first 3 years and high incidences of root-lesion nematodes, but not due to a shortage of water as was expected in annual cropping. Grain yields of all crops were negatively associated with root lesion nematode incidences (Fig. 5). In the first 3 years, soil moisture in plots grown to annual winter wheat was greater than in other rotations from May until harvest (Figs. 3 and 4) indicating that the crop was not able to use available soil moisture. Crop rotation that involved spring barley had very low incidences of the root-lesion nematode and consequently produced high yields.

Table 9. Grain yield of winter wheat, spring wheat, spring barley, and winter peas under different cropping systems at Columbia Basin Agricultural Research Center, Moro, Oregon, 2004-2008. The yield shown is for the crop in italics.

Rotation	Grain yield (bu/acre)				
Annual cropping	2004-05	2005-06	2006-07	2007-08	4-yr mean
Annual *winter wheat*	10.6c	18.7d	30.76ef	20.2bc	20.2e
Annual *spring wheat*	10.1c	37.9bc	32.01e	15.0c	23.9de
Annual *spring barley*	11.6c	64.8a	39.31d	24.2b	34.9c
Two-year rotations[†]					
Conventional fallow-*Winter wheat*	58.0a	59.5a	64.5ab	38.9a	55.2ab
Chemfallow-*Winter wheat*	52.9ab	46.5b	60.6b	41.4a	50.3b
Winter wheat-*winter pea*	9.1c	17.1d	9.5g	-	-
Winter pea-*winter wheat*	40.5ab	33.2c	36.4de	13.2cd	30.8c
Three-year rotations					
Chemfallow-*winter wheat*-spring barley	63.2a	57.9a	65.9a	42.6a	57.4a
Winter wheat-*spring barley*-chemfallow	12.8c	59.2a	35.7de	9.5d	29.3cd
Precipitation (inches)	7.9	16.9	11.1	8.4	

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

Center of Sustainability, Heppner

Grain yield

During the 2007-2008 season, winter wheat after chemical and conventional tillage fallow produced higher yields than annual crops. Under annual cropping, spring barley produced the highest yields followed by winter wheat. No yield was obtained from annual spring soft white wheat because of poor emergence and frost damage. The 4-year (2004-2005 to 2007-2008) average followed the same trend (Table 10). However, on an annualized yield basis, annual spring barley produced the highest grain yields. There were no yield differences between annual winter wheat and annualized yields of winter wheat after either traditional or chemical fallow. Yields of annual Dark Northern Spring wheat were on average higher than those of annual soft white spring wheat. The experiments have now been terminated.

Table 10. Grain yield of winter wheat, spring wheat, and spring barley under different cropping systems at the Center of Sustainability, Heppner, Morrow County, Oregon.

Rotation	Annual cropping†				Two-year rotations†		Precip (in)
Year	Cont. spring barley	Cont. spring wheat	Cont. DNS	Cont. winter wheat	Winter wheat/TF	Winter wheat/CF	Sept-June
2004-05	42	16	23	25	68	71	9.4
2005-06	52	29	28	34	47	56	14.5
2006-07	47	29	25	33	62	56	12.3
2007-08	21	0	16	19	36	36	7.8
Mean†	**41**	**19**	**23**	**28**	**53**	**55**	**11**
Annualized	**41**	**19**	**23**	**28**	**27**	**28**	

(†)DNS = Dark Northern Spring wheat; TF = traditional fallow; CF = chemical fallow

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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.	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Max
80-Yr Avg	75	62	47	39	37	43	51	59	67	74	83	82	111
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	69	74	86	80	95
2007-08	74	59	48	41	38	48	51	54	66	73	84	82	105
2008-09	75	62	52	37	39	41	47	58					
10 Year Average	76	62	48	39	40	45	53	58	65	74	84	83	105
20 Year Average	76	62	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
80-Year Average	46	38	31	26	24	28	32	36	42	48	54	53	-24
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	42	49	58	52	4
2007-08	45	36	29	27	22	30	29	31	45	45	54	54	5
2008-09	45	37	34	20	25	27	29	35					-2
10-Year Average	47	37	30	27	27	28	32	35	43	48	55	54	-6
20-Year Average	47	38	31	27	27	28	32	36	43	48	55	54	-16

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.	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Max
79 Year Average	78	65	49	42	40	46	54	62	71	79	89	88	115
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	72	80	92	86	106
2007-08	78	64	51	43	40	50	53	60	70	76	90	87	109
2008-09	80	66	54	39	41	45	49	61					
10 Year Average	80	66	51	43	43	48	56	62	70	79	90	88	111
20 Year Average	80	66	50	42	43	47	55	63	70	78	89	88	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.	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Min
79 Year Average	43	35	31	27	24	28	32	36	42	47	51	50	-30
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	41	48	55	49	3
2007-08	41	35	29	28	22	30	31	31	43	44	51	52	-2
2008-09	40	32	33	17	25	28	29	34					-17
10 Year Average	43	35	31	28	28	29	33	35	42	47	53	51	-20
20 Year Average	43	35	32	27	27	28	32	36	42	47	53	51	-26

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
79 Year Average	**.71**	**1.36**	**2.09**	**2.06**	**1.95**	**1.52**	**1.74**	**1.53**	**1.50**	**1.23**	**.33**	**.46**	**16.46**
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	.95	1.15	.32	.36	15.33
2007-08	.26	1.30	2.10	2.35	1.79	.63	2.22	.50	1.30	1.33	.12	.58	14.48
2008-09	.12	.21	2.09	2.81	2.05	1.41	2.54	1.77					
10 Year Average	**.59**	**1.35**	**2.25**	**2.10**	**1.87**	**1.59**	**1.86**	**1.46**	**1.58**	**1.21**	**.20**	**.33**	**16.37**
20 Year Average	**.52**	**1.25**	**2.41**	**1.89**	**2.05**	**1.45**	**1.86**	**1.67**	**1.83**	**1.14**	**.30**	**.47**	**16.83**

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
99 Year Average	**.55**	**.93**	**1.69**	**1.66**	**1.61**	**1.15**	**.95**	**.80**	**.84**	**.67**	**.22**	**.28**	**11.35**
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	.34	.55	.04	.45	11.06
2007-08	.24	2.03	1.75	.72	1.28	.41	.64	.35	.72	.30	0	.31	8.75
2008-09	.16	.41	.90	1.38	1.86	1.12	.73	.73					
10 Year Average	**.23**	**.97**	**1.53**	**1.70**	**1.29**	**.97**	**.67**	**.72**	**.85**	**.52**	**.07**	**.28**	**9.80**
20 Year Average	**.30**	**1.00**	**1.60**	**1.47**	**1.50**	**1.05**	**.89**	**.93**	**.99**	**.57**	**.21**	**.30**	**10.82**