Special Report 1054
June 2004

2004 Columbia Basin Agricultural Research Center Annual Report

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Agricultural Experiment Station
Oregon State University
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2004 Columbia Basin Agricultural Research Center Annual Report

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

Promotions and Awards

Scott Oviatt was promoted to Physical Scientist (Category 3). Amy Baker, Linda Baugh, Robert Correa, Patricia Frank, Hero Gollany, Donald Hulick, Tami Johlke, Jennifer Levy, Scott Oviatt, Dave Robertson, Mark Siemens, Christina Skirvin, Katherine Skirvin, and Dale Wilkins received performance awards. John Williams and Stewart Wuest both received Quality Step Increases for outstanding performance. Dave Robertson was presented an Extra Effort Award, and Daryl Haasch received a safety award. Eric Boyle, Kari Dallas, Gretchen Duetschlander, Ben Greenwalt, Christina Skirvin, Sam Womack, and Mandy Wuest received Keepsake Awards for Safety.

Dan Ball was promoted to Professor of Weed Science in the Crop and Soil Science Department.

Staff Changes

There was one addition to the ARS staff during the past year (2003-2004). Dr. Dan Long was selected for the post of Research Leader and joined the staff on January 26, 2004. Temporary employees included Terry Billmeyer, Eric Boyle, Brian Currin, Kari Dallas, Gretchen Deutschlander, Ben Greenwalt, Jennifer Levy, Nick Sirovatka, Christina Skirvin, Allen Wernsing, Sam Womack and Mandy Wuest.

There were few staff changes among the OSU employees at CBARC. The most notable was the retirement of Gloria Eidam, office manager, after 28 ½ years at CBARC. She faithfully served four different superintendents, many scien-tists and a host of technicians and other employees. She made sure our bills were paid, our paperwork was completed, and our paychecks were in order; we thank her all of this and more and we wish her well in retirement. Annette Frye was hired as the new OSU office manager in December; she had previously been with the Coos Bay School District.

Don Wysocki was named as Extension Cereal Specialist on July 1; Don had previously been the Extension Soil Scientist. Don will provide statewide leadership in developing and evaluating Extension education programs on cereal grain systems. He will be developing these programs in partnership with the agricultural industry, other public agencies and colleagues in the state and across the Pacific Northwest.

These programs will encourage the adoption of improved management practices and cropping system strategies that will improve profitability of cereal crops while assuring environmental quality.

Temporary and summer students included: Nathan Adelman, Keely Beech, Andrew Blanc, Stephen Caldwell, Joel Currin, Ashley Freeman, Austin Greenfield, Jeremy Gregory, Shaun Hachquet, Jonathon Jackson, Robert Johlke, Jessica Justus, Michelle Milton, Scott Montgomery, Nick Sirovatka, Joanna Skirvin, Amie Spratling, Tyler Stahl, David Tanner, and Tina Zeckman.

New Projects

OSU scientists and Extension Specialists rely on outside support for many of the research projects they conduct. The grants and contracts received by OSU scientists totaled more than $400,000 in 2003, although the research on many of these grants and contracts will extend for two or more years into the future.

The ARS re-evaluates its national projects on a five-year rotation schedule. After gathering input from local and regional stakeholders a second ARS CRIS (Current Research Information System) project, Cropping Systems and Land Management in Dryland Pacific Northwest, has been approved by the ARS National Program Staff. It is part of the USDA-ARS Integrated Farming Systems National Program (NP 207). The project's duration will be 60 months; John Williams will be the Lead Scientist. Dan Long, John Williams, and Mark Siemens will commit 90 percent of their research efforts to this CRIS; in addition, Hero Gollany will contribute 50 percent of her research effort, and Stewart Wuest and Steve Albrecht ten percent. Mark Siemens initiated a project to determine if improvements in cereal grain quality consistency could be obtained by segregating kernels by size and/or density.

Dr. Dan Long will begin testing advanced optical technology for on-combine sensing of grain quality. In 2004, he will cooperate with two commercial firms that are developing spectroscopic technology for sensing wheat protein concentration from the combine during harvest. Potential uses of grain protein maps include deriving site-specific nitrogen recommendations and predicting straw yield levels from conventional- vs. conservation-tillage systems. This proposed research continues his work started in northern Montana when he was Associate Professor at the MSU Northern Agric. Res. Center, Havre.

Facilities and Equipment

The ARS resurfaced the parking lot. In the main ARS office and laboratory building, energy-saving lighting was installed, a new exhaust system upgraded the fume hood in the chemistry laboratory, exit (safety) light fixtures were replaced, new phones were provided for the main office, and the software for phone system was also upgraded. Design work to upgrade the existing HVAC was begun. In the microbiology laboratory, a new sink and storage cabinet was installed; some electrical circuits were upgraded and backflow devices were also installed.

The ARS laboratory purchases in the past year included a new gas chromatograph (for nitrous oxide, methane and carbon dioxide detection); a new analyzer for determination of carbon, nitrogen, and sulfur; a new component to upgrade the nitrate/ ammonium analyzer; a diluter; and a compressor and vacuum pump for microbiology laboratory. Field data acquisition equipment purchases included an array of time domain reflectrometry (TDR) moisture sensors; new precipitation gauge; turbidity meter and a current meter for the erosion project; and a compact data acquisition system. In addition, a 5 HP portable gas-powered compressor; a 1000 gal. underground water tank; a dockage tester; a pneumatic ring pounder; and a 4x4 Dodge pickup were acquired. The TDR soil moisture measurement system will be used to determine how tillage affects water movement, water storage, and crop water use. The computer laboratory added a new high-speed black-and-white laserjet printer, and Autocad Inventor series software. Safety-related purchases included an automated external defibrillator (AED) for the location and a collaps-a-tainer for mixing pesticides in the field. Also, a new diesel engine was purchased for the plot combine, and a poster-board cabinet was added to upgrade existing facilities.

There were substantial budget reductions to both the Agricultural Experiment Station and Extension Service so there were few major purchases using state funds in 2003. We did purchase new computers for several programs and other important but relatively inexpensive pieces of equipment. We arranged to lease 35 acres of land immediately north of the experiment station to use for direct-seeding research.

Training

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

Outreach

John Williams taught a graduate level class titled Watershed Science & Management in the Department of Regional Planning and Environmental Science, WSU-TriCities campus. Stewart Wuest discussed his research in Biology classes at Pendleton High School; Amy Baker, Tami Johlke, Scott Oviatt, Nick Sirovotka, Katherine Skirvin, and Stewart Wuest represented ARS at Career Day, Outdoor School and Watershed Field Days. John Williams replaced Dale Wilkins as the USDA-ARS (Pendleton) representative and grant proposal reviewer on the USDA – Cooperative State Research, Education, and Extension Service – Solutions to Economic and Environmental Problems in the Pacific Northwest (STEEP) program.

Scientists and Extension Specialists from OSU gave more than 70 different outreach and Extension programs in 2003. The topics ranged from weed control to disease and nematode management to understanding the soil resource to groups that ranged from high school students to farmers to tax assessors.

Visitors

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

- Dr. Mike Jawson of the ARS National Program Staff, Beltsville MD
- Dr. Michael Shannon, Associate Area Director, PWA
- Dr. Daniel Skinner, Research Leader, USDA-ARS, Pullman, WA.

- U.S. Congressman Greg Walden Representative to the 2nd District in Oregon.
- Leaders of the Oregon Wheat Growers League and Oregon Wheat Commission
- Members of the Oklahoma Wheat Commission
- 20 participants of Leadership Pendleton

Seminars

Steve Albrecht coordinated the 2003 OSU/ARS seminar series at the Centers. Seminars included the following topics and speakers:

Preliminary Results from Rainfall Simulation on Rotary Subsoiled Winter Wheat near Harrington, WA by Drs. Stewart Wuest and John Williams, USDA-ARS, Columbia Plateau Conservation Research Center, Pendleton, OR, 11 March 2003.

Biological and Agricultural Research Associated with the Space Shuttle by Ms. Marcie Whittaker, Department of Nuclear Engineering, Oregon State University, Corvallis, OR, 27 March 2003.

Two Years of Field Trials on Malting Barley at CBARC by Dr. Steven Petrie, Columbia Basin Agricultural Research Center, Oregon State University, Pendleton, OR, 3 April 2003.

Observations on Cereal and Legume Research at Ten Research Centers in France, Lebanon, Syria, and Turkey by Dr. Richard Smiley, Columbia Basin Agricultural Research Center, Oregon State University, Pendleton, OR, 15 May 2003.

Tourists' Perspective of a Castle in France, Temple in Lebanon, Aqueduct in Syria, and Palaces in Turkey by Dr. and Mrs. Richard Smiley, Columbia Basin Agricultural Research Center, Oregon State University, Pendleton, OR, 15 May 2003.

Vegetation Establishment and Total Suspended Solid Transport in Gerking Creek by Ms. Lori Spencer, Dept. of Environmental Science and Regional Planning, Washington State University, Tri-Cities, WA, 28 May 2003.

A Systems Approach for Designing Great Plains Rotations by Dr. Randal Anderson, Northern Grain Insects Research Laboratory, USDA-ARS, Brookings, SD, 23 September 2003.
On-Combine and Remote Sensing Estimates of Crop N: Applications to Precision N Management in Wheat by Dr. Daniel S. Long, Northern Agricultural Research Center, Montana State University, Havre, MT, 24 September 2003.

Carbon and Nitrogen Transformations by Soil Bacteria by Dr. Stephan L. Albrecht, Columbia Plateau Conservation Research Center, USDA-ARS, Pendleton, OR, 25 September 2003.

ModWht Revisited: A Training Session on the Theory and Use of the ModWht Model by Dr. Ron Rickman, Dr. Betty Klepper, Sue Waldman (Retired USDA-ARS), Columbia Plateau Conservation Research Center, Pendleton, OR, 20 November 2003.

Liaison Committees

Chairpersons Mark Hales 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. These committees provide a crucial communication link between growers and the research community. We encourage you to contact the Liaison Committee chairs with your concerns and suggestions for improvements regarding any aspect of the research centers.

Expressions of Appreciation

The staff expresses their appreciation to individuals, associations, and corpo-rations that have given special assistance for the operation of experimental research plots during this past year, 2003-2004. 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, the Pendleton Flour Mills, Pendleton Grain Growers, Agrium, Bayer, and Monsanto. We would also like to thank the Umatilla Soil and Water Conservation District, Bev Kopperud, and Ray Denny for their continued support.

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
American Cyanamid Co.
Aventis CropScience
Bank of the West
Bayer Corp.
BASF Corp.
Columbia River Bank
Community Bank
E. I. du Pont de Nemours
Farm Credit Service
FMC Corp.
Inland Chemical Service
Inland Empire Bank
Kuo Testing Labs
Main Street Cowboys
McGregor Co.
Mid-Columbia Bus Co.
Monsanto Co.
Pendleton Flour Mills
Pendleton Grain Growers
Pendleton Main Street Cowboys
Pioneer Implement
Rohm and Haas
UAP Northwest
Walla Walla Farmers Coop.
Western Farm Service
Wheatland Insurance
Wilbur-Ellis

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
Columbia River Bank
Bank of Eastern Oregon
Farm Credit Service
Gustafson
Klamath First Federal
Main Street Cowboys
Mid-Columbia Bus Co.
Mid Columbia Producers
Monsanto Co.
Morrow County Grain Growers
Richelderfer Air Service
Seed Prod +
Sherman Aviation
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, Tom Darnell, 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 Roland Sherman in Columbia County; Aaron Esser and Dennis Tonks in Adams/Lincoln Counties; and Debbie Moberg in Walla Walla County.

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). They have performed field operations, loaned equipment, donated chemicals, forfeited yield, and adjusted their practices to accommodate our experiments. The locations of these off-station plot sites are shown on the map that follows.

We truly appreciate the support and encouragement of growers, organi-zations, 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.

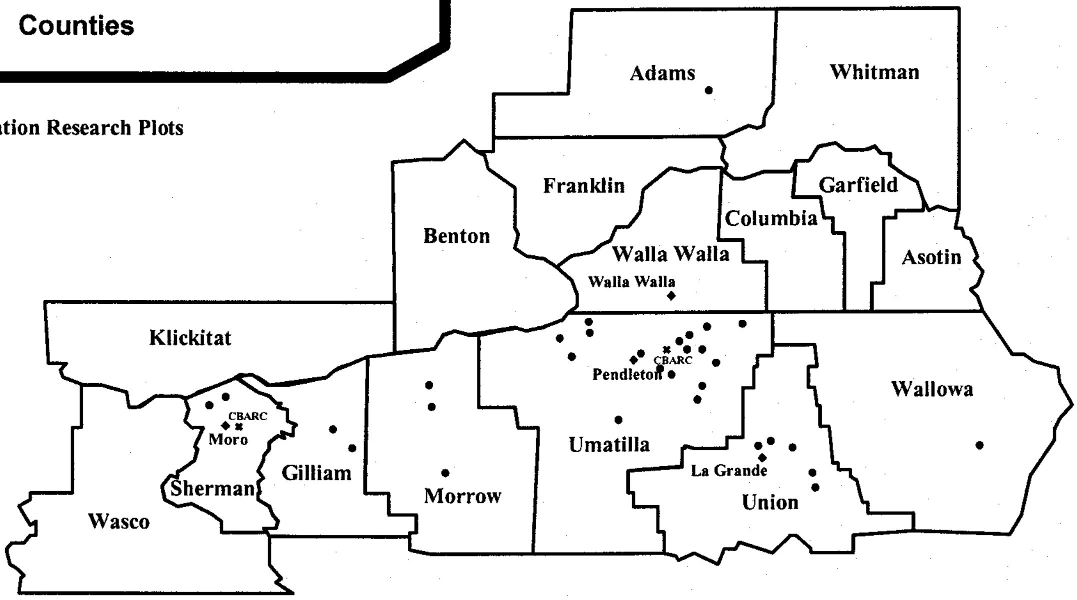
Steve Petrie
Superintendent
OSU-CBARC

Steve Albrecht
Acting Research Leader (3/03 – 1/04)
USDA-ARS-CPCRC

RESEARCH PLOT LOCATIONS

Eastern Oregon - Eastern Washington Counties

- Off-Station Research Plots



ADAMS, WA
Curtis Henning

GILLIAM, OR
Bob Kamerrer
Jeff Nelson

MORROW, OR
Kelwayne Haugewood
Joe McElligott
Chris Rauch

SHERMAN, OR
Bryan McKinney

UMATILLA, OR
John Adams
Charles Betts
Bracher Farms
Cliff Bracher
D-8 Ranches
Davis Farms
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Jim Loiland
Bill Lorenzen
Kent Madison
Pat Maney
Les Owen
Fred Price
Dennis Rae
Clint Reeder
Paul Reeder
Leon Reese
Sherman Reese

UNION, OR
Dale Case
Rod Case
John Cuthbert
Roger Davis
Sam Royce

WALLOWA, OR
Kurt Melville
Tim Melville

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AGRONOMIC CONSIDERATIONS FOR CHEMICAL FALLOW IN DRYLAND WHEAT PRODUCTION

Daniel A. Ball, Larry Bennett, and Larry Lutcher

Abstract

The use of direct seeding for dryland production of winter wheat has the potential to reduce soil erosion, reduce crop production expenses associated with tillage operations, and improve soil quality while maintaining or improving crop yields. In the driest parts of the PNW, a season-long fallow period is a necessary part of most dryland crop rotations, whether conventionally grown or direct seeded. In direct seed systems that require fallowing as part of the overall crop rotation, growers necessarily rely on herbicides rather than tillage to control weeds. The optimum timing of glyphosate applications, and/or the combined use of glyphosate plus herbicides that provide residual soil activity can reduce the overall cost of fallow while maximizing vegetation control. Since tillage is eliminated in chemical fallow systems, it is important to give special consideration to weed management beginning during wheat harvest, and continuing throughout the early chemical fallow period. Early season attention to management of crop residue and control of annual weeds when they are small in size will improve the likelihood of successful season-long chemical fallow. Effective chemical fallow begins during wheat harvest and must be managed throughout the entire fallow period until planting of the next crop. The chemical fallow period can be divided into three periods for the purposes of discussion and management planning. These periods include the harvest and early post-harvest period in the fall, spring and early summer fallow period, and late summer fallow period.

Introduction

In the inland Pacific Northwest (PNW), direct seeding for dryland winter wheat production continues to attract the attention of growers. The use of direct seeding for dryland production of winter wheat has the potential to reduce soil erosion, reduce crop production expenses associated with tillage operations, and improve soil quality while maintaining or improving crop yields. In the driest parts of the PNW, a season-long fallow period is a necessary part of most dryland crop rotations, whether conventionally grown or direct seeded. Fallow periods conserve scarce soil moisture necessary for crop production in the subsequent crop year. Control of volunteer cereals, grass weeds, and broadleaf weeds is critical for successful moisture conservation during these fallow periods. In direct seed systems that require fallowing as part of the overall crop rotation, growers necessarily rely on herbicides rather than tillage to control weeds. The elimination of tillage and the reliance on herbicides during the fallow period is termed chemical fallowing. Effective chemical fallowing typically relies on multiple applications of glyphosate (Roundup®) to maintain season-long control of weeds such as volunteer cereals, downy brome (*Bromus tectorum*), jointed goatgrass (*Aegilops cylindrica*), rattail fescue (*Vulpia myuros*), Russian thistle (*Salsola iberica*), and numerous other weed species. The optimum timing of glyphosate applications, and/or the combined use of glyphosate plus herbicides that provide residual soil activity can reduce the overall cost of fallow while maximizing vegetation control.

Effective chemical fallow begins during wheat harvest and must be managed throughout the entire fallow period until planting of the next crop. The chemical fallow period can be divided into three periods for the purposes of discussion and management planning. These periods include the harvest and early post-harvest period in the fall, spring and early summer fallow period, and late summer fallow period.

Harvest and early post-harvest period: During wheat harvesting, the use of a chaff spreader behind the combine will minimize chaff rows and the subsequent concentration of volunteer wheat and weed growth that occurs within chaff rows. Vegetation control with herbicides is hindered when heavy crop residues and dense vegetation growth prevents adequate herbicide spray coverage. If allowed to grow for an extended period, uncontrolled vegetation within chaff rows can become matted, which prevents adequate herbicide spray coverage. Matted vegetation also can complicate direct seeding operations at the end of the fallow period by hindering uniform seed placement.

If sufficient fall precipitation occurs to allow germination of volunteer cereals and/or weeds, a herbicide application at this time will control vegetation while it is still relatively small, has not become matted, and before it becomes hardened-off by over-wintering conditions. Control of vegetation that has emerged in the fall will facilitate improved vegetation control the following spring. Research conducted near Moro, Oregon, a 13-inch annual precipitation location, illustrates that split applications of glyphosate in the fall and spring provides better control of volunteer wheat and grass weeds than does a single spring application of glyphosate (Table 1).

Table 1. Influence of glyphosate timing and rate on volunteer wheat control, Moro, Oregon.

Treatment [1]	Rate	Timing	Volunteer wheat control
	oz product/acre		(%)
glyphosate/glyphosate	8 / 12	fall / spring	100
glyphosate/glyphosate	8 / 16	fall / spring	100
glyphosate	8	spring	81
glyphosate	12	spring	95
glyphosate	16	spring	98
glyphosate	24	spring	99
glyphosate	32	spring	100

[1] All glyphosate treatments made with Roundup Original® (a 3-lb/gal product), a non-ionic surfactant at 1 qt/100 gal, and ammonium sulfate at 17 lb/100 gal.

In areas where emerging Russian thistle plants present a problem after wheat harvest, control in the fall is often necessary to prevent excessive weed growth. Herbicides containing glyphosate can be effective on small Russian thistle plants. Treatment with paraquat plus diuron (Surefire®) can also provide good effectiveness against post-harvest infestations of Russian thistle.

For late fall, post-harvest herbicide applications for vegetation control in areas with a Russian thistle problem, research has shown that a late fall timing of sulfentrazone (Spartan®) can provide extended control of Russian thistle well into the following spring and summer (Table 2). Sulfentrazone is a preemergence, soil-active herbicide that requires about a half inch of precipitation within 3 to 4 weeks of application to become active in the soil. In low rainfall areas of the inland PNW, spring application of sulfentrazone has not proven to be as reliable for control of Russian thistle as fall application (Table 2). This is due to the reduced probability of sufficient precipitation events in late spring to move the applied sulfentrazone into the soil for activation. In higher rainfall areas, an early spring application of sulfentrazone can provide season-long Russian thistle control if adequate precipitation for soil activation is received after herbicide application. Sulfentrazone needs to be combined with a foliar active herbicide such as glyphosate to control emerged weeds.

Table 2. Russian thistle control with soil residual herbicides, Morrow County, Oregon, 2003.

		Application	Russian thistle control		
Treatments[1]	Rate	timing	May 7, 2003	June 12, 2003	July 6, 2003
	oz product/acre		%	%	%
untreated control	--	--	0	0	0
sulfentrazone	2.7	Fall	85	80	80
sulfentrazone	5.3	Fall	96	93	92
sulfentrazone	2.7	Spring	86	53	37
sulfentrazone	5.3	Spring	93	72	43
atrazine	7.2	Spring	68	10	0
metribuzin	10.7	Spring	72	17	5
LSD (0.05)			18	17	14

[1] All treatments were tank-mixed with a 3-lb/gal glyphosate product at 16 oz/acre. Sulfentrazone applied as Spartan® 75DF , metribuzin as Sencor® 75DF, and atrazine as Aatrex® 90DF.

Spring and early summer fallow period: This is the ideal time for growth of volunteer cereals and cool-season weeds such as downy brome, jointed goatgrass, feral rye, and various broadleaf weeds such as mustards, tarweed, and kochia. An application of glyphosate should be timed to prevent excessive vegetative growth, and before flowering of weeds. Consider the vegetation density and stage of growth when deciding on the appropriate glyphosate rate. PNW research has shown that the specific glyphosate formulation is less important in determining weed control effectiveness than is the actual glyphosate application rate, prevailing environmental conditions at time of application, and the use of necessary surfactants. Some glyphosate formulations require additional surfactant to be effective, others do not. Also, ammonium sulfate (AMS) has been shown to improve effectiveness of glyphosate, particularly with low glyphosate application rates. However, the beneficial effects of AMS in the spray tank solution are lessened as higher rates of glyphosate are used (Table 3).

Table 3. Glyphosate rate and ammonium sulfate (AMS) effects on weed biomass[1] reduction in two study years.

Glyphosate rate	AMS[2]	Pendleton 2001 28 DAT[3]	Pendleton 2002 28 DAT
oz product/acre[4]		--------------- % [5]	-------------
12	WO	97 b	92 c
16	WO	99 a	95 b
24	WO	100 a	99 a
12	W	99 a [6]	95 b
16	W	100 a	96 b
24	W	100 a	98 a

[1] Total weed biomass of volunteer wheat, downy brome, and tumble mustard.
[2] W = AMS added to treatments at 8.5 lb/100-gal spray solution, WO = without AMS.
[3] Days after treatment.
[4] Product rates based on a 3-lb ae/gal glyphosate formulation (ae = acid equivalent).
[5] Percent biomass reduction compared to an untreated control.
[6] Values within the same column followed by the same letters are not significantly different at $P > 0.05$.

Late summer fallow period: Control of weeds during the late summer period can be difficult. Weeds that have escaped control by this time of the season are metabolically inactive due to water and heat stress, thereby making them tolerant to control with herbicides. Dusty conditions can also complicate herbicide effectiveness. For these reasons, it is important to control weeds early in the fallow period when they are young and actively growing. Late germinating summer annuals including Russian thistle, kochia (*Kochia scoparia*), prickly lettuce (*Lactuca serriola*), and horseweed (*Conyza canadensis*) can become a problem during the late summer. Light infestations may not be of particular concern, but a heavy infestation at this time may need to be mowed, or eliminated with tillage to prevent production of weed seeds. There are no consistently effective chemical controls for these late season weed escapes.

Since tillage is eliminated in chemical fallow systems, it is important to give special consideration to weed management beginning during wheat harvest, and continuing throughout the early chemical fallow period. Early season attention to management of crop residue and control of annual weeds when they are small in size will improve the likelihood of successful season-long chemical fallow.

CHLORIDE FERTILIZATION INCREASED WINTER WHEAT AND BARLEY YIELD IN NORTHEASTERN OREGON

Steve Petrie, Pat Hayes, Nathan Blake, Ann Corey, Karl Rhinhart, and Kim Campbell

Abstract

Research on chloride (Cl) fertilization in the Willamette Valley of western Oregon and other western states has shown that wheat yield is often increased by Cl applications. The areas where Cl responses have been reported have either much greater annual precipitation than eastern Oregon or the precipitation occurs primarily in the summer. There has been very little field research on the effect of Cl application to winter wheat and winter barley in the dryland region of eastern Oregon where most of the precipitation occurs in the winter. We established field trials at Moro and Pendleton in the 2001-02 and 2002-03 growing seasons to evaluate the response of winter wheat and winter barley to Cl applications on sites with relatively low soil test Cl values. Chloride was applied as KCl at 0, 50, or 250 lb/acre in 2001 and at 0, 50, or 150 lbs/acre in 2002 at both Moro and Pendleton. Two varieties of winter wheat and two varieties of winter barley were seeded in the fall of 2001. We seeded eight winter wheat varieties (six common and two club varieties) and three winter barley varieties (two feed and one malting variety) in mid-October 2002. All nutrients except Cl were applied based on soil test results. Chloride fertilization increased leaf Cl concentration in wheat and barley in all trials. Chloride fertilization increased winter wheat grain yield, test weight, and kernel weight in 2001-02 at Pendleton and Moro, although the differences were not always statistically significant. Physiologic leaf spot (PLS) was observed in wheat at Moro and Pendleton in 2002-03 and Cl fertilization reduced the severity of PLS at both locations. Varieties responded differently to Cl fertilization at Pendleton but not at Moro. Chloride fertilization increased yield test weight and 1000-kernel weight at Pendleton but not Moro. Winter barley yield was increased by Cl fertilization at Moro in both years and at Pendleton in 2001-02. Chloride fertilization tended to increase test weight and plump kernels and reduce thin kernels.

Key words: chloride fertilization, physiologic leaf spot, winter barley, winter wheat

Introduction

The role of chloride (Cl) in plant nutrition and fertilizer research has an interesting history. The first report that Cl was essential for plant growth and development appeared in 1954 (Broyer et al.) but at that time there was little reason to believe that Cl deficiency would remain anything other a laboratory curiosity. It had proven extremely difficult to establish the essentiality of Cl because it is so widespread in nature and the absolute amount required by plants is relatively small. For many years, agronomists assumed that field crops would not benefit from Cl fertilizer applications.

That notion was challenged in the late 1970's by research conducted at Oregon State University. Winter wheat responses to Cl fertilization were first reported in the Willamette Valley of western Oregon more than 20 years ago. Jackson and his colleagues were among the first to observe

Cl effects on winter wheat yields (Taylor and Jackson 1980) when they reported that Cl applications reduced the incidence and severity of take-all root rot. Christensen et al. (1981) reported that Cl fertilization affected plant water relations and this effect was at least partially responsible for the reduction in take-all root rot. Later, Christensen and Brett (1985) found that Cl^- functioned as a nitrification inhibitor and delayed the conversion of ammonium (NH_4) to nitrate (NO_3). Other work showed that Cl application also affected the response of wheat plants to leaf rust. This work was all conducted in the Willamette Valley and centered on the role of Cl in plant nutrition and its impact on diseases. This work demonstrated that Cl had an impact on plant diseases, soil microbial activity, and plant water relations and, working through these indirect mechanisms, Cl application increased wheat yields.

About this same time, Petrie and Brown (1983) reported that Cl, applied as ammonium chloride (NH_4Cl), potassium chloride (KCl), calcium chloride ($CaCl_2$), or even sodium chloride (NaCl), increased dryland wheat yields in southeastern Idaho in the absence of any observed root diseases.

Most of the field research on Cl fertilizer has been conducted on wheat but Christensen and his colleagues also found that barley responded to muriate of potash (KCl) fertilizer, even on soils testing high in potassium (K). Christensen (personal communication) found that Cl fertilizers often increased kernel weight and test weight.

Field research in Montana, North Dakota, and Kansas as well as the Prairie Provinces of Canada has shown that Cl fertilization can result in economically significant wheat yield responses under summer-rainfall dryland conditions (Carr et al. 2001; Jackson 1998; Lamond and Leikam 2002; Roberts 1999). In some cases, the yield effects were due to the effect of Cl on root and leaf diseases but in other cases, the response was due directly to improved plant nutrition. This research has led to an understanding of the situations in which a yield response is likely based on soil test and/or plant analysis information. Soil test Cl values less than 20 to 40 lb/acre in the top 2 ft of the soil are associated with yield responses to Cl fertilization. Plant analysis has also proven to be a useful guide to plant responses; whole plant samples with less than 0.4 percent Cl may respond to Cl fertilization and crops are quite likely to respond to Cl fertilization when leaf samples have less than 0.12 percent Cl. The likelihood of a Cl response increased as the Cl concentration in the plants decreased. It is important to note that these are all summer rainfall regions in contrast to eastern Oregon where most of the rainfall occurs between October and May.

The Cl ion is negatively charged and it is at least as mobile as nitrate (NO_3^-) ions in the soil solution. Thus, Cl is more readily leached during the winter in the PNW winter rainfall region compared to regions that receive summer rainfall. The soil test values established in other areas may not be appropriate for our region.

Unfortunately, there has been only limited research on cereal responses to Cl fertilization in eastern Oregon. Smiley (1993) conducted a series of field trials on physiologic leaf spot (PLS) of wheat in the early 1990's at the Columbia Basin Agricultural Research Center. His work revealed that PLS is not caused by a pathogen and that tillage, crop rotations, and fertilizer application sources or rates did not affect the disease. He did find that club wheat varieties had less PLS than soft white or hard red wheat varieties. Smiley reported on a foliar fertilizer trial that provided support for the concept that PLS is a Cl-related disorder. He found that application of a foliar fertilizer that contained urea and calcium chloride reduced the incidence of PLS and increased yields while application of a foliar fertilizer with urea but no Cl had less effect on PLS and did not increase grain yields.

Petrie et al.(2003) reported that Cl fertilization increased winter barley yields in preliminary trials at both Pendleton and Sherman station. Fertilization with Cl increased flag leaf Cl concentration and grain yield at both Pendleton and Sherman station and increased test weight and plump kernels at Pendleton.

The objective of this research was to investigate the effects of Cl fertilization on dryland winter wheat and barley yields in eastern Oregon. Specifically, we examined the effects of Cl fertilizer on PLS of winter wheat, and the effects of Cl fertilizer on both winter wheat and barley yield and quality.

Materials and Methods

Winter wheat and winter barley, 2001-02

We seeded 'Stephens' and 'Rohde' winter wheat at 25 seeds/ft^2 and 'Strider' winter feed barley and 'Stab 47', an advanced winter malt barley line, at 22 seeds/ft^2 on October 5 at Pendleton and on October 11 at Moro using a Hege grain drill with five openers spaced 12 inches apart. Preplant soil test values are shown in Table 1. Chloride was applied at 0, 50, or 250 lb/acre as KCl, broadcast on the soil surface immediately after seeding. Individual plots were 5 by 20 ft and the treatments were arranged in a randomized complete block design with four replications. The entire plot area at Pendleton received 80 lb of N/acre and 15 lb of S/acre as anhydrous ammonia and ammonium thiosulfate while the plot area at Moro received 50 lb of N/acre and 10 lb of S/acre. Flag leaf samples were collected at heading and analyzed for Cl. The plots were harvested using a Hege plot combine. The grain from the plots was weighed to estimate yield and subsamples were collected for determination of test weight and percent plump and thin kernels.

Winter wheat and winter barley, 2002-03

Moisture conditions in the fall of 2002 were poor and the trials were established by "dusting in" the seed and waiting for rain to bring about germination and emergence. The winter wheat and barley trials were established adjacent to each other and all cultural practices were the same. The trials were harvested using a Wintersteiger plot combine and yields were estimated. Subsamples of the harvested grain were used to measure grain quality parameters.

Wheat We seeded eight varieties of winter wheat (two club types ['Coda' and 'Temple'] and six common types ['Beamer', 'Madsen', 'Stephens', 'Tubbs', 'Weatherford', and WPB 470]) at 25 seeds/ft^2 on October 8 into dry soil at Pendleton using a five-row Hege grain drill with hoe-type openers spaced 12 inches apart. Chloride was applied at 0, 50 or 150 lb/acre as KCl prior to planting using a nine-row Hege grain drill with double disk openers placed 6.5 inches apart to place the fertilizer just below the soil surface. Individual plots were 5 by 20 ft and the treatments were replicated four times in a randomized complete block design. The entire area received 110 lb of N/acre and 10 lb of S/acre as anhydrous ammonia and ammonium thiosulfate. The same varieties were seeded at Moro on October 15 using a four-row Hege grain drill with hoe openers spaced 14 in apart. The KCl was applied prior to planting using the Hege grain drill to place the KCl just below the soil surface. The entire plot area at Moro received 35 lb of N/acre and K_2SO_4 to supply K and S. Plant samples consisting of the upper half of the youngest fully expanded leaf at late tillering and the flag leaf at boot stage were collected and analyzed for Cl. The plants were rated for PLS by visual estimation using a 1-5 rating scale where 1 = no PLS and 5 = severe PLS.

Barley We seeded two varieties of winter feed barley ('Strider' and 'Kold') and one advanced line of winter malting barley ('Stab 7') at 22 seeds/ft^2 on October 8. All other procedures were the same as described for the wheat.

Results and Discussion

Winter wheat, Moro, 2001-02

This was a "screening trial" and we used relatively high rates of Cl compared to the rates used in other regions to assure that sufficient Cl had been applied. 'Stephens' common winter wheat and 'Rohde' club winter wheat were seeded because they differ markedly in the potential to exhibit physiological leaf spot (PLS); club wheat varieties are much less likely to exhibit PLS than common wheat varieties (Smiley 1993). No PLS was observed at Moro in the 2001-02 growing season. Nonetheless, Cl application resulted in consistent but non-significant yield increases of both 'Stephens' and 'Rohde' winter wheat (Table 2). Application of 50 lb of Cl/acre increased the yield of 'Rohde' club wheat by 2.6 bu/acre and applying 250 lb of Cl/acre resulted in a 4.1 bu/acre yield increase, a 16 percent yield increase. The yield of 'Stephens' wheat was increased by 5.4 bu/acre when 50 lbs of Cl/acre was applied.

Chloride fertilization resulted in consistent but non-significant increases in test weight of 'Stephens' wheat but had no effect on test weight of 'Rohde' wheat. Application of Cl reduced the 1000-kernel weight of 'Rohde' wheat while it increased the 1000-kernel weight of 'Stephens' wheat.

Table 1. Soil test values in the top foot of the soil.

Site and year	pH	N[1]	P	K	SO_4-S	Cl
		lb/acre	----------	---------- ppm	----------	----------
Moro, 2001	6.5	18	28	362	4.6	4.0
Pendleton, 2001	6.6	26	13	393	9	10.6
Moro, 2002	6.2	130	36	--	2.3	5.5
Pendleton, 2002	5.4	99	26	588	8	4.0

[1]Total NO_3-N in top 4-5 ft of the profile + NH_4-N in top ft of profile

Table 2. Effect of Cl fertilization on winter wheat yield, test weight, and 1000-kernel weight at Moro, Oregon, 2001-02.

Cl rate	Yield	Test wt.	1,000-kernel wt.	Yield	Test wt.	1,000-kernel wt.
		'Rohde'			'Stephens'	
	Bu/acre	Lb/bu	grams	Bu/acre	Lb/bu	grams
0	26.3	56.5	33.0	31.6	53.5	37.5
50	28.9	56.7	31.3	37.0	55.6	39.1
250	30.4	56.8	31.5	34.6	55.6	40.8
$LSD_{0.10}$	5.5	ns	ns	ns	ns	3.1

Winter wheat, Pendleton, 2001-02

Application of Cl fertilizer also resulted in consistent yield increases of both 'Stephens' and 'Rohde' wheat, although the differences were not always statistically significant (Table 3). The yield of 'Stephens' common wheat was increased from 61.9 to 68.6 and 70.2 bu/acre by 50 and 250 lb Cl/acre, respectively. The yield of 'Rohde' wheat was increased from 54.2 to 56.2 and 59.9 bu/acre by 50 and 250 lb of Cl/acre, respectively. Chloride fertilization increased the 1000-kernel weight of both 'Stephens' and 'Rohde' wheat but Cl fertilization had no consistent effects on test weight for either variety.

Winter Wheat, Moro, 2002-03

We seeded eight winter wheat varieties at Moro in the fall of 2002, six common wheat and two club wheat varieties. Averaged across the eight varieties in the study, Cl application increased the leaf Cl concentration in samples collected at late tillering and at boot stage indicating that the Cl was taken up by the plants (Table 4). Field research in other states has shown that whole plant samples with less 0.4 percent (4,000 ppm) may respond to Cl fertilization while plants are likely to respond to Cl fertilization when leaf samples have less than 0.12 percent Cl. Plant tissue Cl concentrations of the untreated control plants were intermediate between these values indicating that Cl may have been sufficient for the crop. Nonetheless, Cl fertilizer did tend to reduce the PLS rating. Winter wheat grain yield at Moro was unaffected by Cl fertilization in the 2002-03 growing season. The average yield, test weight, and 1000-kernel weights are shown in Table 4; none of the eight varieties grown at Moro responded to Cl fertilizer.

Table 3. Effect of Cl fertilization on winter wheat yield, test weight, and 1,000-kernel weight at Pendleton, Oregon, 2001-02.

Cl rate	Yield	Test wt.	1,000-kernel wt.	Yield	Test wt.	1,000-kernel wt.
		'Rohde'			'Stephens'	
	Bu/acre	Lb/bu	grams	Bu/acre	Lb/bu	grams
0	54.2	61.4	29.9	61.9	59.1	37.1
50	56.2	59.1	31.1	68.6	59.0	41.3
250	59.9	61.1	31.6	70.2	59.1	42.0
$LSD_{0.10}$	4.2	ns	ns	8	ns	2.2

Table 4. Effect of Cl fertilization on mean leaf Cl concentration, PLS rating, grain yield, test weight, and kernel weight of eight varieties of winter wheat at Moro, Oregon, 2002-03.

Cl rate	Leaf Cl concentration		PLS rating[1]	Grain yield	Test wt.	1,000-kernel wt.
lb/acre	---------- ppm ----------			bu/acre	lb/bu	---- grams ----
	Late tillering	Boot stage				
0	3,070	2,980	2.4	57.1	57.8	32.3
50	5,155	6,565	2.0	58.4	58.1	33.0
150	5,810	7,725	2.0	57.5	58.1	33.5
$LSD_{0.10}$	640	580	0.4	ns	ns	ns

[1]PLS rating scale 1-5 where 1=no PLS and 5 = severe PLS

Winter Wheat, Pendleton, 2002-03

Averaged across the eight varieties in the study, Cl fertilizer application increased leaf Cl concentration at both late tillering and at boot stage, markedly reduced the PLS rating, and increased grain yield, test weight, and 1000-kernel weight (Table 5). Mean leaf Cl concentration tended to be less at Pendleton than at Moro at comparable Cl fertilizer rates. The leaf Cl concentration in the untreated control plants was within the range where a yield response was possible. The mean PLS rating was reduced from 3.6 to 1.6 by the application of 50 lbs of Cl/acre and to 1.3 by the application of 150 lb of Cl/acre. Application of Cl fertilizer at 50 lbs of Cl/acre increased mean grain yield by more than six bushels and increased test weight by 1 lb/bushel. Kernel weight was also increased significantly by the application of 50 lb of Cl/acre.

In contrast to the trial at Moro where there were no differences between the eight varieties, the varieties responded differently to the Cl fertilizer at Pendleton (Table 6). The club varieties exhibited less PLS than the common varieties. ‘Coda’ had no PLS and ‘Temple’ had only a low PLS rating in the absence of Cl fertilization.

Table 5. Effect of Cl fertilization on mean leaf Cl concentration, PLS rating, grain yield, test weight, and kernel weight of eight varieties of winter wheat at Pendleton, Oregon, 2002-03.

Cl rate	Leaf Cl concentration		PLS rating[1]	Grain yield	Test wt.	1,000-kernel wt.
lb/acre	---------- ppm ----------			bu/acre	lb/bu	---- grams ----
	Late tillering	Boot stage				
0	2,245	1,950	3.3	72.0	55.8	27.5
50	4,260	4,020	1.6	78.6	56.8	29.9
150	5,550	5,640	1.3	79.6	57.1	30.3
$LSD_{0.10}$	285	430	0.2	4.0	0.7	0.7

[1]PLS rating scale 1-5 where 1=no PLS and 5 = severe PLS

Neither club wheat variety had any PLS when Cl fertilizer was applied. There were noticeable differences among the common wheat varieties in their response to Cl fertilizer. Chloride fertilization essentially eliminated the PLS exhibited by several varieties, such as 'Madsen' and 'Tubbs'. Chloride fertilization markedly reduced the PLS rating of some varieties such as 'Stephens' and 'Tubbs' without increasing the yield. In other cases, such as 'Madsen' and 'Weatherford', a marked reduction in PLS rating was accompanied by a significant yield increase when Cl was applied.

Winter Barley, Moro, 2001-02

We also examined the effects of Cl fertilization on winter feed and malting barley in a preliminary screening trial at Moro. This trial was located immediately adjacent to the winter wheat trial. Application of Cl fertilizer at either 50 or 250 lb of Cl/acre markedly increased the leaf Cl concentration of both 'Strider' feed barley and 'Stab 47' malting barley (Table 7). The yield of both 'Strider' feed barley and 'Stab 47' malting barley was increased by Cl fertilizer but Cl fertilization had little impact on the test weight or the percentage of plump and thin kernels.

Table 6. Effect of Cl fertilization on physiologic leaf spot rating and grain yield of eight varieties of winter wheat at Pendleton, Oregon, 2002-03.

Variety	Cl fertilization Rate					
	0 lb Cl/acre		50 lb Cl/acre		150 lb Cl/acre	
	PLS[1]	Grain yield	PLS[1]	Grain yield	PLS[1]	Grain yield
		Bu/acre		Bu/acre		Bu/acre
Coda	1.0	69.3	1.0	79.6	1.0	73.4
Temple	1.3	70.6	1.0	74.2	1.0	85.9
Beamer	5.0	62.7	3.0	72.5	2.5	66.0
Madsen	3.5	69.7	1.0	82.8	1.0	83.9
Stephens	4.3	70.5	2.3	71.4	2.0	70.3
Tubbs	3.0	75.9	1.0	76.3	1.0	78.3
Weatherford	4.3	68.5	1.7	83.4	1.3	76.9
WPB 470	3.2	91.0	2.0	88.6	1.3	95.7

[1]PLS rating scale 1-5 where 1=no PLS and 5 = severe PLS

Table 7. Effect of Cl fertilization on winter barley leaf Cl concentration, yield, test weight, and kernel size distribution at Moro, Oregon, 2001-02.

Variety	Cl rate	Leaf Cl	Yield	Test wt.	Plump kernels	Thin kernels
	Lb/acre	-- ppm --	Lb/acre	Lb/bu	-- % --	-- % --
'Strider'	0	3,720	3,220	47.5	52.3	4.0
	50	7,460	3,545	47.3	57.0	2.8
	250	10,835	3,640	48.0	56.3	4.5
'Stab 47'	0	3,350	2,950	49.7	60.0	4.0
	50	6,575	3,245	49.5	60.7	4.7
	250	9,910	3,290	49.7	59.3	6.3
$LSD_{0.10}$		1,665	310	ns	ns	ns

Winter Barley, Pendleton, 2001-02

Fertilization with Cl dramatically increased Cl leaf concentration of 'Strider' and 'Stab 47' barley (Tale 8). Chloride fertilization significantly increased the yield of 'Strider' feed barley but not the yield of 'Stab 47' malting barley. These results contrast with those from Moro where the yield of both varieties was increased by Cl fertilization. The reasons for the different responses at the two sites are not clear; both varieties took up similarly increasing amounts of Cl as the Cl application rate increased. It is possible that some other unidentified factor limited yield of 'Stab 47' malting barley at Pendleton. The test weight of both varieties was consistently increased by Cl fertilizer but the increases were not significantly different. Plump kernels are a key kernel quality factor for malting barley and Cl fertilization significantly increased plump kernels in 'Stab 47' malting barley.

Winter Barley, Moro, 2002-03

Application of Cl fertilizer markedly increased leaf Cl concentration at both late tillering and boot stage (Table 9). The Cl concentration fell by about 50 percent between late tillering and boot stage in those plants that received Cl fertilizer. Chloride fertilization increased the yield of 'Strider' and 'Stab 7' but actually reduced the yield of 'Kold' although the reduction was not significant. The effects on test weight were mixed; Cl fertilization had no effect on the test weight of 'Kold', consistently but not significantly increased test weight of 'Strider', and significantly reduced the test weight of 'Stab 7'. Chloride had no significant effect on plump kernels but did significantly reduce thin kernels of 'Strider' and 'Kold' and consistently reduced the thin kernels of 'Stab 7'.

Table 8. Effect of Cl fertilization on winter barley leaf Cl concentration, yield, test weight, and kernel size distribution at Pendleton, Oregon, 2001-02.

Variety	Cl rate	Leaf Cl	Yield	Test wt.	Plump kernels	Thin kernels
	Lb/acre	-- ppm --	Lb/acre	Lb/bu	-- % --	-- % --
'Strider'	0	2,650	4,980	51.3	86.5	1.2
	50	4,185	6,400	52.6	88.5	1.0
	250	6,420	5,890	52.4	89.5	1.0
'Stab 47'	0	2,700	3,860	50.9	61.7	2.5
	50	3,950	3,745	51.3	80.2	1.5
	250	7,400	3,490	51.2	78.7	2.0
$LSD_{0.10}$		650	840	ns	9.8	0.8

Table 9. Effect of Cl fertilization on winter barley leaf Cl concentration, yield, test weight, and kernel size distribution at Moro, Oregon, 2002-03.

Variety	Cl rate	Leaf Cl concentration		Yield	Test wt.	Plump kernels	Thin kernels
		Late tillering	Boot stage				
	Lb/acre	---------- ppm ----------		Lb/acre	Lb/bu	-- % --	-- % --
'Strider'	0	2,450	2,370	4,345	45.9	42	5
	50	7,800	3,365	4,660	47.7	55	2
	150	9,390	4,470	4,935	48.0	64	2
$LSD_{0.10}$		425	365	310	ns	ns	3
'Kold'	0	2,775	2,405	4,835	50.7	42	7
	50	7,850	3,430	4,200	50.4	58	4
	150	10,060	4,480	4,375	50.2	53	4
$LSD_{0.10}$		1,250	390	ns	ns	ns	3
'Stab 7'	0	3,325	2,830	3,870	50.5	56	5
	50	7,175	4,675	3,975	49.6	51	2
	150	9,740	6,020	4,360	49.1	47	2
$LSD_{0.10}$		1,095	525	425	0.6	ns	ns

Winter Barley, Pendleton, 2002-03

Chloride application at Pendleton signify-cantly increased leaf Cl concentration but had no effect on the mean yield, test weight, or kernel size distribution of the three winter barley varieties (Table 10); there were no significant effects on the yield or test weight of the individual varieties.

Table 10. Effect of Cl fertilization on winter barley leaf Cl concentration, yield, test weight, aand kernel plumpness at Pendleton, Oregon, 2002-03.

Cl rate	Leaf Cl concentration		Yield	Test wt.	Plump kernels	Thin kernels
	Late tillering	Boot stage				
Lb/acre	---------- ppm ----------		Lb/acre	Lb/bu	-- % --	-- % --
0	2,100	2,230	6,120	52.3	46	5
50	4,155	3,490	6,260	52.0	41	6
150	5,455	5,480	5,925	51.6	51	5
$LSD_{0.10}$	180	725	ns	ns	ns	ns

Summary and Conclusions

A series of field trials was conducted at Moro and Pendleton during the 2001-02 and 2002-03 growing seasons to assess the effect of Cl fertilization on physiologic leaf spot (PLS) of winter wheat and the yield and quality of winter wheat and winter barley. There was a relatively severe occurrence of PLS in the 2002-03 growing season. We found that Cl application reduced the PLS rating of common wheat varieties but not club type wheat; the club wheat varieties we grew had almost no PLS regardless of the Cl treatment. In some varieties, but not all, the reduction in PLS rating was accompanied by a significant yield increase. Fertilization with Cl dramatically increased leaf Cl concentrations in all studies. We found that Cl fertilization frequently increased yield of both winter wheat and winter barley but that the responses were not well correlated with soil test Cl values. Chloride fertilization tended to increase test weight and 1000-kernel weight in winter wheat and test weight and kernel plumpness in winter barley but there are many exceptions as well. This work shows that Cl fertilization holds the promise of increased yields and quality but there is still much we need to learn about Cl fertilization in eastern Oregon.

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COMPETITION FOR WATER BY WINDBREAK TREES: DISTANCE OF IMPACT ON WHEAT YIELD

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Abstract

Windbreaks are important for conservation of energy and resources on many farms. Trees and shrubs in windbreaks also compete with adjacent crops for water, nutrients, and light. Roots and leaves of some species also release compounds that retard or prevent growth of other plant species. An experiment at the Columbia Basin Agricultural Research Center at Pendleton, Oregon, provided an opportunity to quantify the distance to which the yield of winter wheat was reduced by competition along a tree line. Wheat yield was reduced by 28 percent in a zone 100 ft from a row of mature, 56-ft-high Austrian pine trees. The zone of visual effect on wheat growth extended at least 120 ft from the tree trunks, and 100 ft horizontally beyond the tips of the longest branches. Wheat growth was also visually affected up to 35 ft from a row of shorter (14 ft high) blue spruce trees. The importance of these observations is discussed with respect to yield on farm fields, the potential for improving yield by pruning tree roots, and the experimental design for research experiments in fields adjacent to windbreaks.

Key words: allelopathy, water stress, wheat, yield, windbreak trees

Introduction

One or more lines of narrowly spaced trees are used to slow the velocity of wind moving through many farmsteads. Windbreak tree planting became popular as a way to reduce wind erosion following the dust-bowl era. Windbreaks have also been advocated for reducing heat loss around buildings, protecting livestock, providing wildlife habitat, reducing sound transmission from roads to nearby buildings, and trapping wind-blown snow. Windbreaks were widely planted along driveways, fence lines, and around rural farmsteads during the 1950's, 1960's, and 1970's.

Windbreak trees compete for resources such as water, light, and nutrients, and the zones of resource competition extend into nearby crops, pastures, and landscape plantings. However, there is less understanding about the distance to which the competition occurs, and the magnitude of impact that the trees have on productivity of adjacent crops. This information could become useful when accurate estimates of crop yield are required for fields that include significant areas bordered by windbreak plantings.

The competition between windbreak trees and adjacent crops may occur as far as three times the height of the tree (Kort, 1988; Sudmeyer and Scott, 2002; Sudmeyer et al. 2002a, Sudmeyer et al. 2002b). The competition is, of course, strongly influenced by prevailing soil and climatic factors in the region. In dryland regions of Australia it is widely recommended that farmers prune the roots of windbreak trees to reduce the impact on crops within the three-times-height zone adjacent to the tree line. The pruning apparently does not reduce tree performance or health, and improves crop yields in fields bordering the windbreaks.

During 2003, we had an opportunity to observe the magnitude of competition for resources affecting a gradient in measured wheat yield near a windbreak at the Columbia Basin Agricultural Research Center (CBARC), at Pendleton, Oregon. This paper reports findings from a seed treatment experiment that provided information relating to the extent of yield reduction in winter wheat adjacent to a windbreak.

Methods

Eleven seed treatment variables were evaluated on 'Stephens' soft white winter wheat at CBARC-Pendleton, where mean annual rainfall (20-yr; 1981-2000) is 17.9 inches. The soil is a Walla Walla silt loam. The trial was planted into an area maintained as a winter cereal/summer fallow rotation. Wheat was planted at 25 seeds/ft^2 into 5- by 40-ft plots with a Hege plot drill equipped with a cone seeder and five disk-openers spaced at 12 inches. Wheat was planted on October 23, 2002 at 1.5-inch depth into moist soil. The experimental design was a randomized complete block with seed treatments replicated six times. Replicates of 40-ft-long plots were aligned east-to-west, and perpendicular to the orientation of a windbreak consisting of Austrian pine trees (*Pinus nigra*). The trees were planted at 14-ft intervals in 1967 and, in 2003, had an average height of 56 ft, with a range of heights from 52 to 63 ft. The border of the experiment nearest the tree line was placed 70 ft from the tree trunks.

Data included grain yield and test weight for the wheat crop. Additional measurements were reported by Smiley et al. (2004). Data were analyzed by analysis of variance. An aerial photo of the station was taken on June 12, 2003 (Fig. 1). The tree-wheat interaction was clearly visible on the aerial photograph but was not detected at ground level. The distance to which the wheat crop was visibly impaired could be measured from the aerial photograph and compared with the average yield for treatments in each replicate of the seed treatment experiment.

Results

Growth and yield were limited by drought conditions at CBARC-Pendleton during both 2002 and 2003. "Growing-season" (Sep-Aug) precipitation deviated from the 20-yr mean by –27 percent during 2002 and by –10 percent during 2003. Spring (Mar-May) precipitation during 2002 deviated from the 20-yr mean by –32 percent during 2002 and by –58 percent during 2003.

The 2002-2003 early winter remained dry but late-winter and spring rainfall was plentiful until April, after which no rain fell. Rainfall amounts (in inches) for each month from September 2002 through July 2003 were as follows; 0.2, 0.6, 1.1, 3.1, 3.3, 2.2, 2.2, 1.8, 1.0, 0 and 0. Grain filling occurred under very dry and hot conditions.

Winter wheat stands (plants/ft of row) 2 months after planting did not differ ($P < 0.05$) among seed treatment variables or replicates. Diseases were not considered to be of limiting severity or incidence. Grain yields and test weights were acceptable for the region and year (Fig. 1). Yields and test weights differed significantly among replicates but not among treatments within each

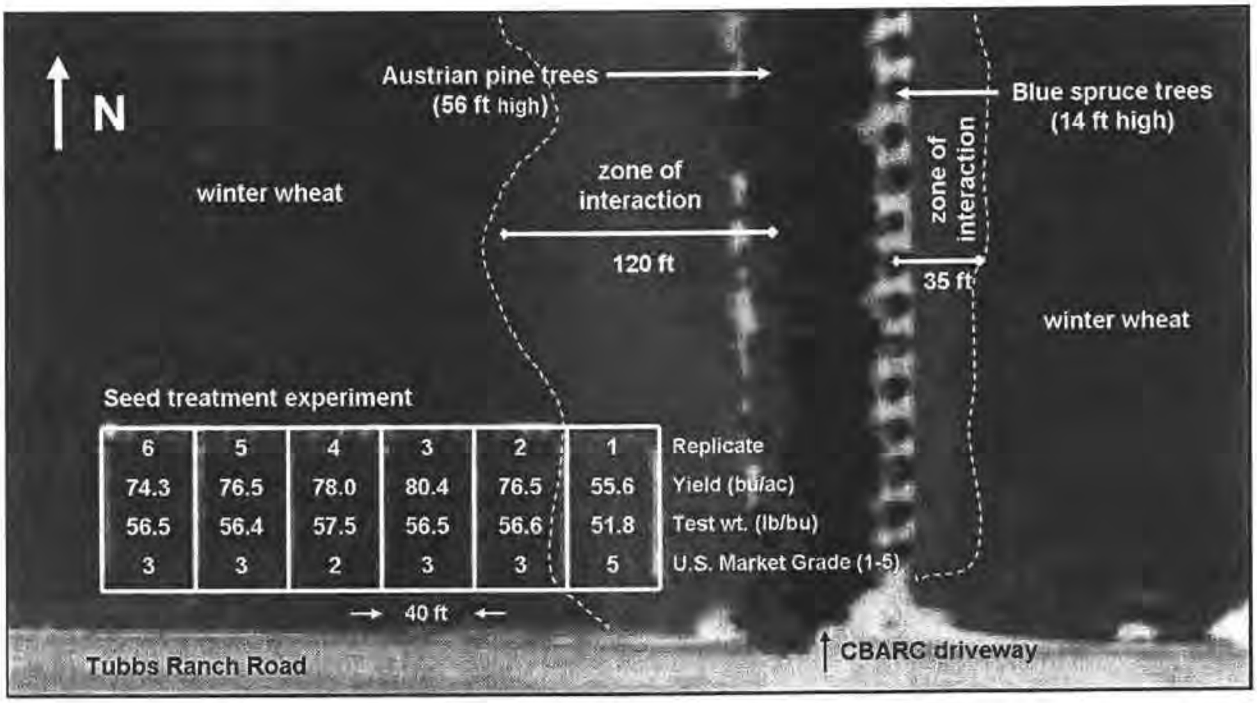

Figure 1. Aerial photograph of the visually apparent tree-crop interaction for winter wheat crops growing adjacent to two rows of trees (each row with a different height) at the Columbia Basin Agricultural Research Center (CBARC) near Pendleton, Oregon, on June 12, 2003. The boxed diagram highlights an experimental area (55 by 240 ft) composed of 6 replicates of 11 seed treatment variables growing in 5- by 40-ft plots oriented in the east-west direction.

replicate. There was a distinct reduction in yield (28 percent) and test weight (4 lb/bu) in replicate number one, compared to the other five replicates. Replicate one covered the zone from 70 to 110 ft from the trunks of the Austrian pine trees.

The visible effect of what was presumed to be drought stress in the wheat, as seen on the aerial photograph, extended to a distance of about 120 ft from the tree line, or approximately 10 ft into replicate two. This distance represented a competitive effect of the trees that extended a horizontal distance of 2.1 times the average height of the trees. Branches of the tallest tree had a radius of 23 ft. The zone of visible crop competition therefore extended about 100 ft beyond the tips of the longest tree branches.

The aerial photo also shows effects on wheat by Colorado blue spruce trees (*Picea pungens*) in a more recently planted windbreak across the road from the seed treatment experiment discussed here. Trees in the blue spruce windbreak were planted at 15-ft intervals during 1991 and were thinned to 30-ft spacing during 2001. The blue spruce trees are currently 14 ft high (range of 10 to 17 ft), and had a visible influence extending 35 ft (2.5 times the average tree height) into the wheat crop.

Discussion

Without the aerial photograph, we would not have noticed the effects the windbreak trees were having on the adjacent crops. These effects were not apparent at ground level. The reduction in yield of crops in replication one clearly demonstrate the effect of windbreak trees on adjacent crops. In our situation, the effect of Austrian pine extended an average horizontal distance of 2.1 times the height of trees. Other scientists (Kort 1988, Sudmeyer and Scott 2002, Sudmeyer et al. 2002a, Sudmeyer et al. 2002b) reported tree influences extending from 1.5 to 3 times the height of trees. Variations in the zones of influence could be attributed to tree species and to prevailing soil and climatic factors of the region.

Water availability is the major limiting factor influencing crop yields in eastern Oregon. We strongly suspect that windbreak trees reduced yield of adjacent crops largely through reducing the soil water available to the crops. With an obviously bigger and more extensive root system, the pine trees have an enormous competitive advantage over the shallow and less extensive crop roots. Neutron attenuation methods will be used to test this assumption in the spring of 2004. Sudmeyer et al. (2002b) attributed the reduction in yield of crops adjacent to pine (*Pinus pinaster*) and eucalyptus (*Eucalyptus globulus*) windbreak trees to water stress.

Other factors including shading, nutrition, and allelopathy may also affect crops growing adjacent to windbreak trees. Shading was assumed to have minimal effects in the observations reported in this paper. The trees at Pendleton shaded part of the crop during the morning but the crop was in full sunlight during the afternoon. Wheat on the east side of the windbreak became shaded only during late afternoon during the summer. Moreover, Sudmeyer et al. (2002b) concluded that competition for nutrients and light appeared to have little effect on wheat yield near windbreaks in Western Australia.

Allelopathy is the production of biochemicals that benefit or adversely affect other plants. Allelopathy, if present, could adversely influence the crop adjacent to windbreak trees. The lack of understory growth around the Austrian pine and Colorado blue spruce could be an indication of adverse allelopathic effects. Red pine (*P. densiflora*) and black pine (*P. thumbergii*) have been found to have strong adverse allelopathic effects on other surrounding plants (Rizvi et al. 1993). More work is needed to determine the influence of allelopathy on adjacent crops.

Based on these results, it is likely that yields of adjacent crops will be reduced whenever they are closer than 120 ft from the tree trunks, or about 100 ft from the closest branches of mature trees. It is especially important that the wider-than-anticipated zone of competitive interaction be considered when research and demonstration experiments are established near windbreaks. Experiments should either be separated from a mature windbreak by approximately 150 ft, or the experimental design should be established, as in our research, to ensure that the variability due to competition will be minimized by replicates oriented perpendicular to the tree line.

Additionally, the wider-than-anticipated zone of competition near windbreak trees could be put to positive use for investigations of drought tolerance, disease intensity, or other factors. The concept for the experimental design would be opposite that used for line-source irrigation studies, in which experimental variables are replicated perpendicular to an irrigation line for the purpose of monitoring plant growth, disease, or other factors under progressively lower levels of available water. This would, however, require a better understanding of the phenomenon observed in this experiment. Specifically, it will be important to be more certain that the variability was indeed mostly or entirely related to availability of water rather than to interactions including nutrition, shading, or allelopathy.

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EVALUATING CHICKPEA (GARBANZO BEAN) FOR ADAPTABILITY TO EASTERN OREGON

Stephen Machado, Christopher Humphreys, Brian Tuck, and Mary Corp

Abstract

Seven chickpea (*Cicer arietinum* L.) varieties were evaluated for suitability to eastern Oregon conditions. The chickpeas, six *kabuli* and one *desi*, were sown in mid-April 2002 and 2003 at the Columbia Basin Agricultural Research Center (CBARC) in Pendleton and Moro, Oregon. Data on plant stand, plant height, disease, phenology, and bean yield were collected. 'Myles', the only *desi* chickpea, produced the highest bean yield under both annual and fallow cropping systems. Unfortunately, *desi* chickpeas are low value chickpeas in the United States. The *kabuli* varieties produced higher yields and bigger beans when soil moisture was adequate (after fallow), but most produced lower bean yield and smaller beans when grown following wheat in a drought year. 'Sinaloa' appears to be the only *kabuli* that is well adapted to low soil moisture conditions. 'Sinaloa' produced >80 percent of grade A beans under both low and high yield potential conditions. The other *kabuli* varieties produced a high percent of grade A beans only under high yield potential conditions. The *desi* chickpea, 'Myles', produced feed and grade C beans. To obtain both high bean yield and a high percentage of grade A beans under both low and high yield potential conditions, we recommend 'Sinaloa'. The other *kabuli* varieties are best grown under high yield potential conditions. If bean yield is the only important factor, then 'Myles' is recommended for both low and high yield potential conditions.

Key words: adaptability, bean size, chickpea, desi, garbanzo, kabuli

Introduction

The reduction of green pea production due the closure of Agrifrozen Foods, Inc. in Walla Walla, Washington in 2000 and the decline in contract acres of Chiquita Processed Foods, LLC in Milton-Freewater, Oregon has led to a search for a new legume crop in eastern Oregon. Chickpea has the potential to replace peas in the traditional wheat pea rotation. Being a relatively new commercial legume crop to northeastern Oregon, there is limited information on chickpea varieties adapted to this region. Chickpeas are classified as either *desi* (small-seeded) or *kabuli,* also called garbanzo (large-seeded) types. The *desi* chickpeas predominate in the Indian subcontinent while the *kabuli* chickpeas predominate elsewhere. *Kabuli* chickpeas dominate American production because of their high value as an ingredient at salad bars (Saxena and Singh 1987, Muehlbauer 1993, Singh and Saxena 1999). However, there is a small but steadily increasing production of *desi* chickpeas. The small amount of *desi* chickpea produced is currently marketed to ethnic communities in large cities. However, there are prospects of expanding production for export (Muehlbauer 1993). The objective of this experiment was to evaluate different chickpea varieties for adaptability to growing conditions in eastern Oregon.

Methods

To determine chickpea varieties adapted to eastern Oregon, seven varieties, namely 'Dwelley', 'Sinaloa', 'Evans', 'Myles', 'Sanford', 'Sierra', and 'CA99901604W', were sown at 3 seeds/ft^2 in mid-April of 2002 and 2003 at the CBARC, Sherman Experiment Station in Moro (11-inch rainfall) and at the CBARC, Pendleton Experiment Station in Pendleton (16-inch rainfall). With the exception of 'Myles', a *desi* chickpea, all varieties were *kabuli* chickpeas.

The chickpeas were grown under conventional tillage following wheat at Pendleton and after fallow at Moro. Data on plant stand, days to flowering, days to maturity, plant height, disease, bean yield, and bean size were obtained. Plant stand was obtained by counting plants along 3-ft sections of two rows from each plot. Days to flowering and maturity were recorded when 50 percent of plants in each plot had flowered or matured. Disease ratings were obtained by estimating the percent of plants per plot that were diseased. Plant samples were sent to the pathologist (Dr. R. Smiley) for diagnosis. Plant height was measured just before harvest. A plot combine was used to harvest the chickpeas. The chickpeas were graded by passing them through sieves. In 2002, beans that did not pass though sieve no. 22/64 were classified as grade A and those that passed through sieve no. 22/64 but did not pass through sieve no. 18/64 were classified as grade B. Beans that passed through sieve no. 18/64 were classified as feed. In 2003 we adopted a more stringent grading system where beans were classified as grade A if they did not pass through sieve no. 22/64; grade B if beans did not pass through sieve no. 20/64; grade C if beans did not pass through sieve no. 18/64; and feed grade if beans passed through sieve no. 18/64. On average, grade A beans sell for $0.18-0.23/lb and grade B beans sell for $0.10-0.15/lb. The C and feed grade can sell for $60-70/ton (Ferrel 2004).

Results and Discussion

In 2002, Pendleton and Moro received 13.0 and 8.4 inches of precipitation, respectively. In 2003, precipitation was higher at both Pendleton (15.4 inches) and Moro (9.3 inches). Because 2002 was a drought year, fallow moisture had a significant effect on bean yield. Bean yields were in general higher at Moro (after fallow) than at Pendleton (recrop) in this year. In 2003, precipitation was probably adequate for annual cropping at Pendleton.

CBARC, Pendleton

Bean yield: In 2002, the *desi* chickpea, 'Myles', produced the highest yield, followed by 'CA99901604W' (Fig. 1). Bean yields from the other varieties were not significantly different from each other and were about 600 lbs/acre lower than the yield of 'Myles'. Despite being grown following wheat in a drought year, 'Myles' produced more than twice the yield of the other varieties. The reasons for the differences in bean yield between 'Myles' and the other varieties were not so apparent. Plant density did not influence bean yields since there were no significant differences in plant counts among the varieties (Table 1). There were some significant differences in plant height among the varieties (Table 1). Bean yields, however, were not significantly correlated (r = -0.28) with plant height. Disease incidences involving combinations of *Fusarium solani*, *F. oxysporum*, the bean leafroll, and alfalfa mosaic viruses (Table 1) appear to have influenced bean yields. 'Myles' and 'Sanford' were less affected by disease than the other varieties. Disease, however, only explained about 18 percent (r = -0.42) of yield variation, indicating that there were other factors with greater about 12 days earlier (in July) than other varieties and probably avoided increasing drought stress experienced in August when the other varieties matured. It is also probable that 'Myles' produced the highest yields through drought resistance.

In 2003, 'Sinaloa' and 'Myles' produced the highest yields (Fig. 2). The yields of the other varieties were not significantly different from each other. Yield was not significantly correlated to either plant stand ($r = 0.23$) or plant height ($r = -0.21$). 'Myles' and 'Sinaloa', which produced the highest yields, reached maturity earlier than the other varieties (Table 1). This indicates that there could be a yield advantage in maturing before drought and heat stresses increase. Disease incidences were not as high as in 2002 and were not recorded.

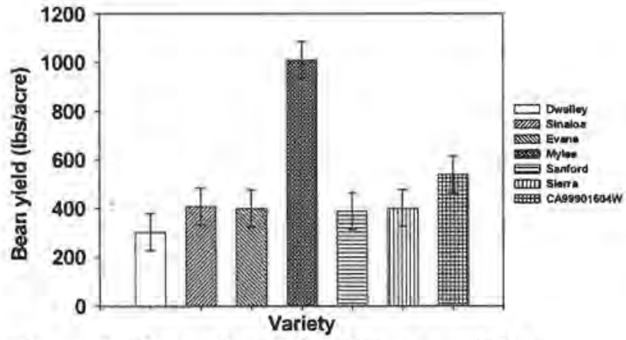


Figure 1. Bean yield of chickpea varieties at CBARC, Pendleton, Oregon, 2002. Bars represent standard error.

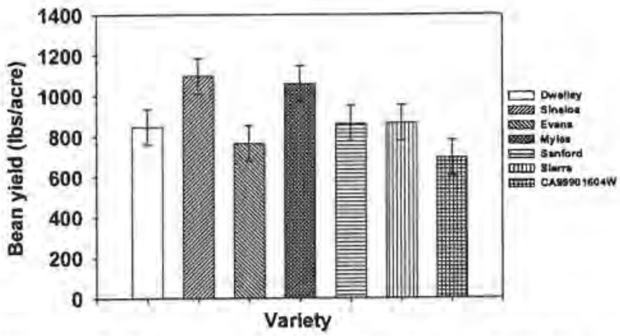


Figure 2. Bean yield of chickpea varieties at CBARC, Pendleton, Oregon, 2003. Bars represent standard error.

Table 1. Plant stand, height, and disease incidence of different chickpea varieties at CBARC, Pendleton, Oregon, in 2002 and 2003.

	2002			2003		
Variety	Plants/ft^2	Plant ht (in)	Disease (%)	Plants/ft^2	Plant ht (in)	Maturity (days)
Dwelley	3.3a[1]	15.4a	36.3ab	4.1ab	13.1ab	96
Sinaloa	3.1a	11.9c	46.3a	3.8b	13.5ab	90
Evans	3.3a	15.7a	48.8a	3.9ab	12.9b	96
Myles	3.2a	13.6b	12.5d	5.3a	11.3c	84
Sanford	3.5a	15.9a	17.5cd	3.8b	13.4ab	96
Sierra	3.3a	15.9a	27.5cb	3.8b	13.4ab	96
CA99901604W	2.6a	13.0bc	25bcd	3.7b	13.6a	96

[1]same letter indicates that means are not significantly different ($P < 0.05$).

Bean size: Although the *desi* chickpea, 'Myles', produced the highest bean yield, its small bean graded as feed in 2002 (Fig. 3). It is, therefore, a low value crop that has few markets in the United States. A huge market, however, exists in India, Parkistan, and North Africa where the beans are used in a variety of dishes (Saxena and Singh 1987, Singh and Saxena 1999). Of the *kabuli* chickpeas, 'Sinaloa' was the only variety that produced >80 percent grade A beans in 2002 (Fig. 3). The breeding line 'CA99901604W' and 'Sierra' produced about 60 and 65 percent grade A beans, respectively (Fig. 3). The rest of the varieties had lower percentages of grade A beans (Fig. 3). This was probably due to drought stress caused by low 2002 crop-year rainfall coupled with low soil moisture conditions created by the previous wheat crop. Among the *kabuli* chickpeas, grain size of 'Sinaloa' was least affected by low soil moisture. In 2003, a wetter year, 'Dwelley', 'Sinaloa', and 'CA99901604W' produced beans that were >80 percent grade A (Fig. 4). The remaining three *kabuli* varieties averaged 70 to 80 percent grade A beans (Fig. 4). 'Myles', the *desi* variety, produced mostly grade C and feed-grade beans (Fig. 4).

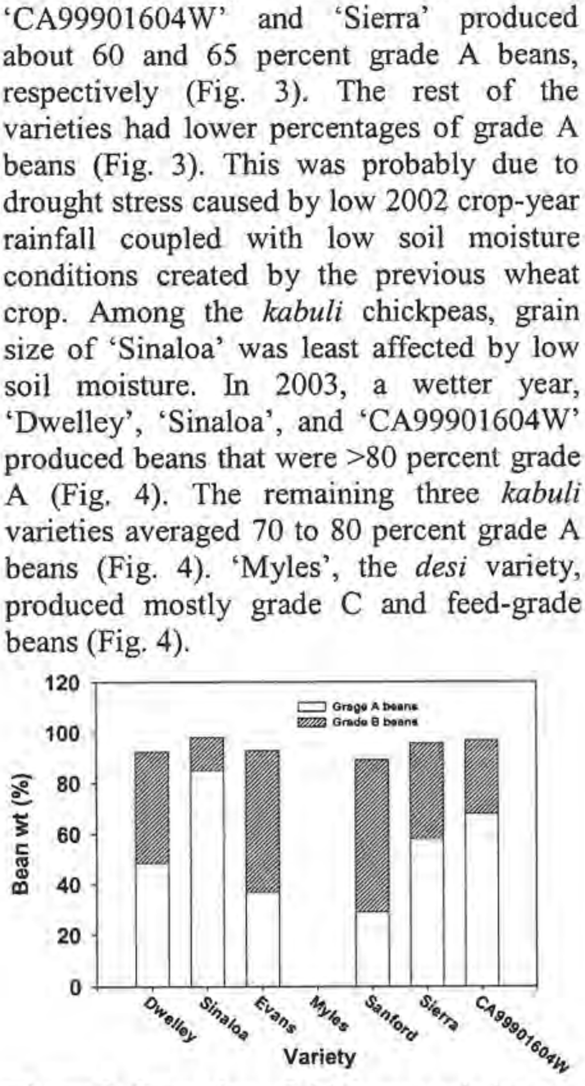
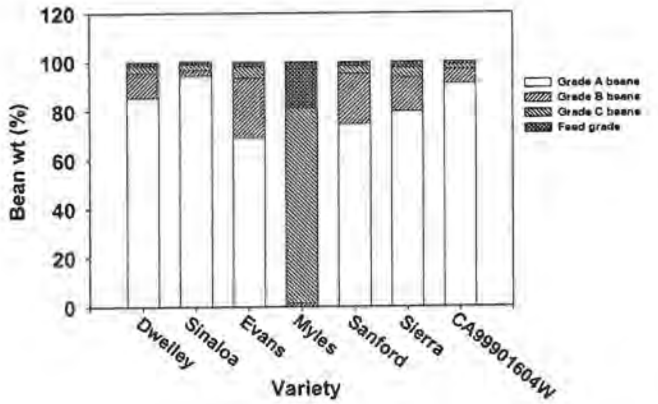


Figure 3. Bean size of chickpea varieties at CBARC, Pendleton, Oregon, 2002.



4. Bean size of chickpea varieties at CBARC, Pendleton, Oregon, 2003.

CBARC, Moro

Bean Yield: As at Pendleton, 'Myles' produced the highest bean yields at Moro in 2002 (Fig. 5). The yields of the rest of the varieties were not significantly different from each other and were about 200 to 300 lbs/acre lower than the yield of 'Myles'. The bean yields of the *kabuli* varieties were about 200 lbs/acre higher than at Pendleton, probably because they were grown on previously fallow land at Moro. Plant stand, plant height, and disease (Table 2) were not significantly different among varieties and consequently these parameters cannot explain differences in bean yields. 'Myles' matured about 8 days earlier than other varieties and could have escaped increasing drought conditions experienced at the end of the season. In 2003, bean yields were not significantly different among all the varieties (Fig. 6). 'Dwelley', however, produced the highest yield, followed by 'Myles'. Once more, plant stand and height were not significantly correlated with bean yield.

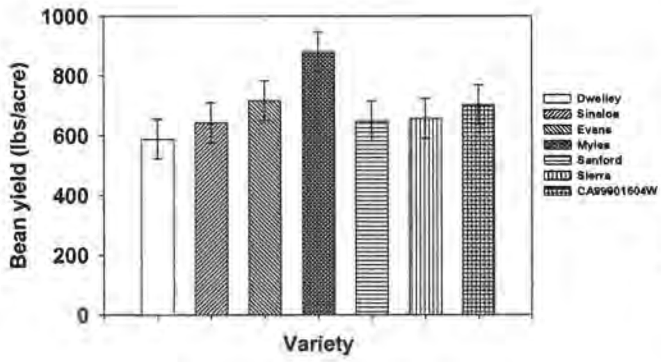


Figure 5. Bean yield of chickpea varieties at CBARC, Moro, Oregon, 2002. Bars represent standard error.

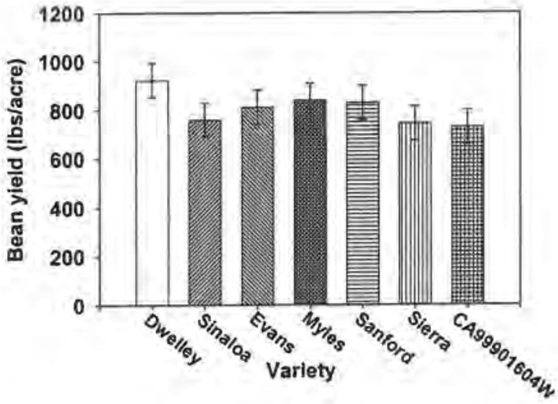


Figure 6. Bean yield of chickpea varieties at CBARC, Moro, Oregon, 2003. Bars represent standard error.

Table 2. Plant stand, height, and disease incidence of different chickpea varieties at CBARC, Moro, Oregon, in 2002 and 2003.

	2002			2003		
Variety	Plants/ft^2	Plant ht (in)	Disease (%)	Plants/ft^2	Plant ht (in)	Maturity (days)
Dwelley	2.7a[1]	12.3a	26.3a	3.7a	12.3a	106
Sinaloa	2.4a	13.3a	25.0a	3.1a	12.0ab	100
Evans	2.4a	12.8a	28.8a	3.7a	12.0ab	106
Myles	2.8a	11.3a	25.0a	3.9a	11.5b	98
Sanford	2.4a	11.5a	21.3a	3.3a	12.3a	106
Sierra	2.8a	13.3a	21.3a	3.0a	12.5a	106
CA99901604W	2.6a	12.4a	25.0a	2.5a	12.4a	106

[1]same letter indicates that means are not significantly different ($P < 0.05$).

Bean size: At Moro, beans produced by 'Myles', the *desi* chickpea, were too small to be classified as grade A or B in both years. The beans were classified as feed or grade C (Figs. 7, 8). In contrast to Pendleton, all the *kabuli* chickpeas produced >80 percent grade A beans at Moro in 2002 (Fig.7). This was probably because there was enough moisture following fallow to minimize drought stress. In 2003, all *kabuli* varieties except 'Evans' and Sanford' produced >80 percent grade A beans (Fig. 8). 'Sinaloa' produced the highest percent of grade A beans during this year.

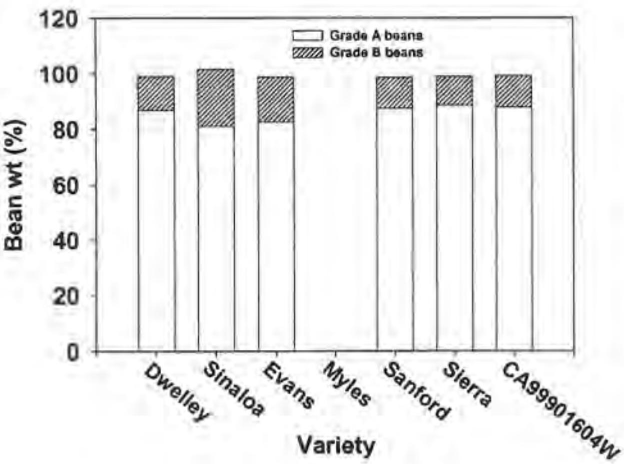


Figure 7. Bean size of chickpea varieties at CBARC, Moro, Oregon, 2002.

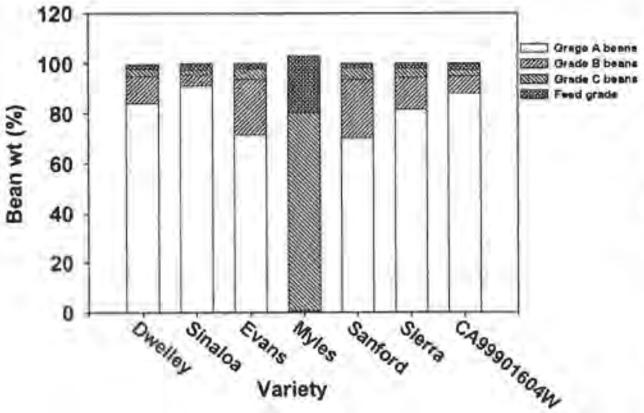


Figure 8. Bean size of chickpea varieties at CBARC, Moro, Oregon, 2003.

Variety adaptability

To determine the overall adaptability of the chickpea varieties to eastern Oregon, bean yields and bean size of varieties from the two sites and two years were combined and analyzed for trends using regression analysis.

Bean yield: Figure 9 shows mean yield of each variety compared to the mean yield of all varieties evaluated in each experiment at Moro and Pendleton in 2002 and 2003. The cropping systems practiced at Moro and Pendleton sites coupled with precipitation received created conditions with relatively low and high yield potential. For instance, the effect of fallow at Moro in 2002, a drought year, created growing conditions with high yield potential. In contrast, annual cropping at Pendleton created growing conditions with low yield potential during this year. In 2003, higher precipitation at Pendleton and Moro created growing conditions with high yield potential. Reference to low and high yield potential below, therefore, is not site specific but refers to the growing conditions experienced by the varieties.

'Dwelley' responded poorly under conditions of low yield potential and yielded close to the trial mean under conditions of high yield potential (Fig. 9). Although below the trial mean, 'Sinaloa' responded better under conditions of low yield potential and above the trial mean under conditions of high yield potential (Fig. 9). 'Evans' expressed poor response to both low and high yield potential conditions (Fig. 9). 'Myles' demonstrated wide adaptability to low and high yield potential conditions and maintained similar yield levels under both environments (Fig. 9). 'Sanford' and 'Sierra' represent varieties that responded poorly to low yield potential conditions and produced yield equal to the trial mean under conditions of high yield potential (Fig. 9). 'CA99901604W' yielded above the trial mean under low yield potential conditions and responded poorly under high yield potential conditions (Fig. 9).

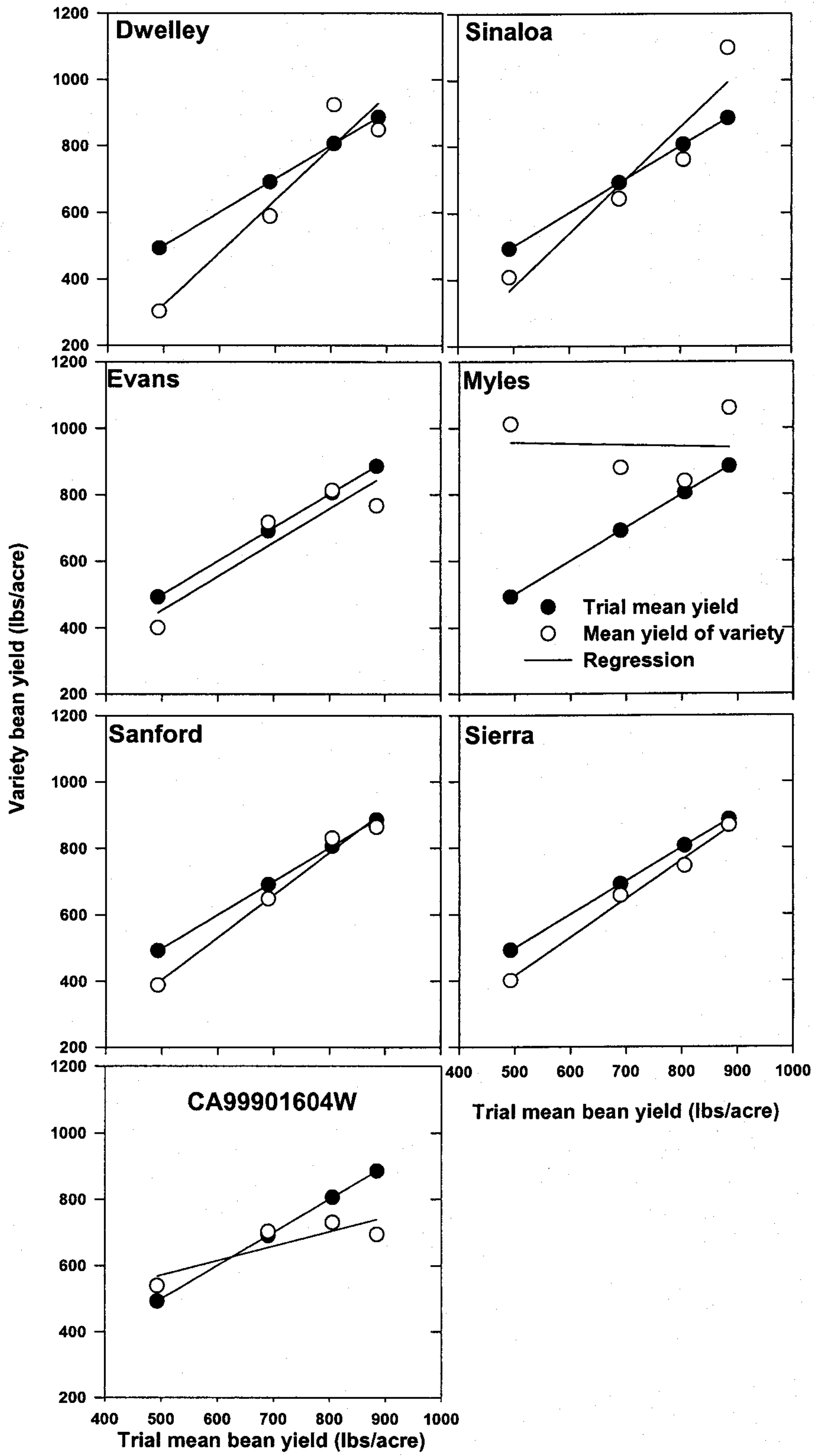


Figure 9. Bean yield response of each chickpea variety relative to trial mean bean yield at CBARC, Oregon, 2002-2003.

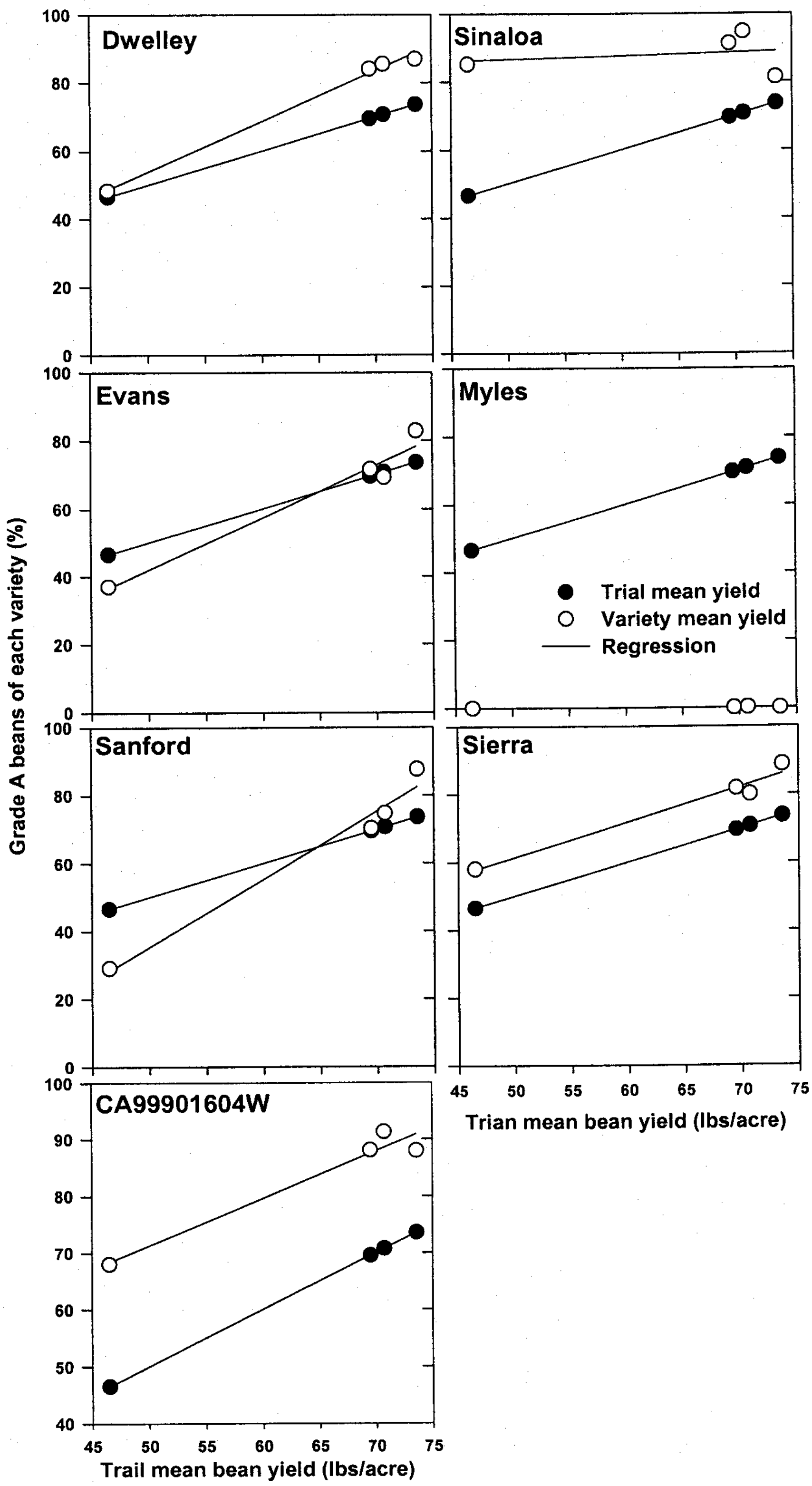


Figure 10. Grade A bean size response of each chickpea variety relative to trial mean grade A bean size at CBARC, Oregon, 2002-2003

Bean size: Profit margins can be increased by producing high yield with a high percentage of grade A beans. A suitable variety, therefore, should posses both attributes. Figure 10 shows the percent of grade A beans for each variety regressed against the mean percent of grade A beans of all the varieties evaluated at Moro and Pendleton in 2002 and 2003. The percentage of grade A beans for 'Dwelley' equaled the trial mean (<50 percent) under low yield potential conditions and was >80 percent under high yield potential conditions (Fig.10). 'Sinaloa' expressed wide adaptability and produced >80 percent grade A beans under both low and high yield potential conditions (Fig. 10). 'Evans' and 'Sanford' responded poorly under low yield potential conditions and slightly above the trial mean under high yield potential conditions (Fig. 10). Being a *desi*, 'Myles' did not produce any grade A beans (Fig. 10). 'Sierra' and 'CA99901604W' responded better than the trial mean under both conditions but the percentage of grade A beans under low yield potential conditions was lower than under high yield potential conditions (Fig. 10).

Conclusions

The *kabuli* varieties produced higher yields and bigger beans when soil moisture was adequate (after fallow and in a wetter year) but most produced lower bean yield and smaller seed when grown following a wheat crop under low rainfall conditions. The *kabuli* chickpeas command premium prices in the United States. 'Sinaloa' appears to be the only *kabuli* that is well adapted to low soil moisture conditions. To obtain both high bean yield and a high percentage of grade A beans under both low and high yield potential conditions, 'Sinaloa' is recommended. The other *kabuli* chickpeas should be grown mostly under high yield potential conditions. If bean yield is the only important factor, then the *desi* chickpea, 'Myles', should be grown under both low and high yield potential conditions. 'Myles' produced exceptionally high yields under low yield potential conditions. It appears to be well adapted to the eastern Oregon environment and yields well under both annual and fallow cropping systems. Unfortunately, *desi* chickpeas are small-seeded and are currently low value beans in the United States. However, the potential exists for exporting *desi* chickpeas to India and Pakistan where they are in demand. India alone requires about 700,000 tons a year although it is the world's largest producer. Canada has capitalized on this market and now exports about 220,000 tons annually to the Indian subcontinent.

Acknowledgements

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LESION NEMATODES REDUCE YIELD IN ANNUAL SPRING WHEAT

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Abstract

High numbers of lesion nematodes (*Pratylenchus neglectus* and *P. thornei*) are present in many annual cropping systems in low-rainfall regions of the Pacific Northwest. Associations between lesion nematodes and grain yield were examined in 13 experiments by growing spring wheat varieties that are susceptible or resistant to lesion nematodes and by treating or not treating soil with a nematicide. Yield was inversely related to lesion nematode populations in 7 of 11 experiments where preplant *Pratylenchus* populations were greater than 400/lb of soil. Compared to two *Pratylenchus*-susceptible varieties, a resistant spring wheat variety had more stable yield at high *Pratylenchus* populations, and had lower rates of *Pratylenchus* reproduction inside the root tissue. The nematicide improved yield in each of seven experiments where preplant *Pratylenchus* populations were high and where soil water was also adequate for adequate wheat yield. The nematicide had no effect on yield in six experiments where *Pratylenchus* populations were low and/or water was limited. This paper presents the first clear and compelling evidence that lesion nematodes cause economic damage to cereal crops in the Pacific Northwest.

Key words: crop rotation, lesion nematode, *Pratylenchus neglectus*, *Pratylenchus thornei*, spring wheat

Introduction

Most wheat in Oregon and Washington is produced in a 2-year rotation of winter wheat and summer fallow. Most of the production acreage receives 10 to 16 inches of annual precipitation. Many wheat-fallow rotations are vulnerable to unacceptable levels of water erosion, and also contribute to concerns regarding quality of air and water. Interest in conservation tillage systems has led to the conversion of land formerly in winter wheat-summer fallow rotation to spring wheat and barley planted annually without tillage. Productivity of annual cereals can be restricted by soilborne plant pathogenic fungi that cause diseases such as Rhizoctonia root rot, Pythium root rot, take-all, and Fusarium crown rot (Smiley 1996, Paulitz et al. 2002;), and by insect pests such as Hessian fly (Smiley et al. 2004b).

Lesion nematode populations can increase dramatically when dryland fields are shifted to a higher intensity of cereal cropping. The most damaging species in rainfed semiarid agriculture are *Pratylenchus thornei* and *P. neglectus*. These species have been shown to reduce wheat yields in Colorado and Utah in the United States, and in Australia, Canada, Israel and Mexico (Nicol et al. 1999, Nicol 2002, Nicol et al. 2003). To determine if this also occurs in the Pacific Northwest (PNW), we surveyed nematode populations in agricultural fields in eastern Oregon and Washington during 1999 and 2000 (Smiley et al. 2004a). Much higher populations of lesion nematodes occurred in fields cropped 3 of every 4 years, or annually, compared to fields cropped during alternate years (i.e., winter wheat-summer fallow rotation). Potentially damaging populations of *P. thornei* and/or *P. neglectus* occurred in soils and roots collected from more than 40 percent of fields cropped more than 50 percent of the years. However, nematode populations per se are poor predictors of damage by *Pratylenchus*. Yield constraints from root damage depend on the nematode species and numbers in roots; crop species, variety, growth stage, and rotation; tillage management; and soil temperature, moisture, and texture. High numbers of lesion nematodes do not necessarily equate to a high potential for damage. Sheedy et al. (1997) reported that grain yield was the most sensitive indicator of wheat response to *Pratylenchus* species.

The objective of this research was to investigate relationships between grain yield and lesion nematode populations in non-irrigated annual spring wheat in eastern Oregon. We used experimental procedures that would provide direct comparisons with research already conducted with dryland wheat in Australia.

Method

Yield response associated with root damage from lesion nematodes in Oregon was evaluated using Australian varieties that differ in susceptibility and tolerance to *P. neglectus* and *P. thornei* (Talavera and Vanstone 2001). We conducted 13 experiments in annual cropping systems at three locations in Sherman and Umatilla counties from 2001 to 2003. Most tests were conducted by treating or not treating each variety with aldicarb insecticide/nematicide, which suppresses damage by lesion nematodes (Taylor et al. 1999).

Australian varieties used in this research had been individually characterized for resistance and tolerance response to both *P. neglectus* and *P. thornei*. Resistance is described as the plant's ability to restrict nematode reproduction, resulting in fewer nematodes compared to populations in roots and soil following production of susceptible varieties. Tolerance is described as the plant's ability to produce adequate yield regardless of the numbers of nematodes in soil or in roots; yields of intolerant varieties are strongly limited by high nematode populations. Resistance and tolerance are, therefore, measures of genetically distinct plant responses. Varieties can be susceptible and tolerant, susceptible and intolerant, resistant and tolerant, or resistant and intolerant. Each of these reactions can differ with respect to *P. neglectus* and *P. thornei*; a specific response to one of these nematodes can be quite different than that for the other species.

Australian wheat varieties included 'Krichauff', 'Machete', and 'Spear'. 'Krichauff' is moderately resistant to and moderately tolerant of *P. neglectus* and moderately susceptible to *P. thornei*. 'Krichauff's level of tolerance to *P. thornei* does not appear to have been reported. 'Machete' and 'Spear' are susceptible and intolerant to both *Pratylenchus* species. To determine the impact of Australian wheat varieties that led to differing populations of lesion nematodes in soil, during 2002 each experimental site was uniformly planted to 'Zak', a PNW-adapted spring wheat variety resistant to Hessian fly. 'Zak' had not been characterized for responses to lesion nematodes.

Wheat seed was treated with fungicides to suppress seed rot and seedling damping-off. In half of the plots in 10 experiments conducted during 2001 and 2003, aldicarb (Temik 15G®) was mixed with the seed at the time of planting, at a rate of 3.8 lb ai/acre. Aldicarb was not applied to 'Zak' in the three experiments during 2002.

Experiments consisted of 5.5- by 20-ft plots with wheat variety and aldicarb treatments arranged in randomized complete blocks replicated three times during 2001 and nine times during 2003. Identical experiments were planted at multiple locations each year. Soils at all locations were silt loams. Herbicide applications were uniform across all plots within each experiment. Fertilizer (16-20-0-14) was applied by either surface-broadcast application prior to planting or by banding 1 inch below the seed at the time of planting. Fertilizer rates varied in response to soil tests and standard practices in each region. Grain was harvested during July and August.

Locations and sites

Location is the term that describes the three host facilities for these experiments: the Hill Farm, and the Pendleton and Sherman (at Moro) Stations of the Columbia Basin Agricultural Research Center (CBARC). *Site* is the term that describes the exact physical space occupied by each experiment. Site 1 for a location designates a series of experiments over the same physical space for each of the years specified. Site 2 designates a different physical space where a second experiment was conducted at that location. Table 1 describes treatments and planting details for 13 experiments at five sites (three locations). Additional details are as follows.

Hill Farm: Three experiments were performed on the Hill Farm 8 miles southeast of Pendleton, where annual precipitation averages about 16 inches. The field had a history of annual cropping without tillage. During 2001, the site was planted to five spring wheat varieties, treated or not treated with aldicarb, with three replicates (30 plots). Nematode populations were determined for all plots. Yield relationships for two of the five varieties, 'Krichauff' and 'Machete', are included in this report (i.e., 12 plots). During 2002, the 30-plot site was planted uniformly to 'Zak', without aldicarb, and sampled corresponding to treatments applied during 2001. During 2003, the experiment at this site was expanded to 36 plots, with two varieties planted, with or without aldicarb, using nine replicates for each treatment.

Moro: Six experiments were conducted 1 mile southeast of Moro, where annual precipitation averages 11 inches. The Moro-1 site had been planted annually to spring wheat without tillage starting in 1996. Experiments at the Moro-1 site were identical to those described for the Hill Farm. During 2003, experiments with 'Krichauff' and 'Spear', treated or untreated with aldicarb, were also planted at a nearby site (Moro-2) where three adjacent blocks had been planted for 2 consecutive years to chickpea, safflower, or spring wheat.

Pendleton: Four experiments were conducted 9 miles northeast of Pendleton, where annual precipitation averages 17.4 inches. The Pendleton-1 site had been planted without tillage to spring or winter wheat starting in 1997. Experiments at the Pendleton-1 site were identical to those described for the Hill Farm and Moro-1 sites. During 2003, the experiment at the Pendleton-1 site was duplicated at an adjacent site (Pendleton-2) planted to chickpea during 2 preceding years.

Table 1. Crop management information for 13 experiments examining the relationship between nematode populations and spring wheat yield at three non-irrigated low-rainfall locations in eastern Oregon.

Location and site [a]	Year	Varieties planted	Aldicarb [b]	Tillage	Planting detail: Date	Depth	Temp [c]	Previous crop [d]: 1-yr	2-yr
						in.	*°F*		
Hill Farm	2001	Krichauff, Machete	yes	none	20 Mar	0.8	54	Ca	Ww
	2002	Zak	no	none	14 Mar	1.0	45	Sw	Ww
	2003	Krichauff, Machete	yes	none	11 Apr	0.6	55	Sw	Sw
Moro-1	2001	Krichauff, Machete	yes	none	23 Mar	1.3	48	Sw	Sw
	2002	Zak	no	none	18 Mar	1.3	36	Sw	Sw
	2003	Krichauff, Machete	yes	chisel	10 Apr	2.0	63	Sw	Sw
Moro-2									
chickpea	2003	Krichauff, Spear	yes	none	10 Apr	2.0	63	Cp	Cp
safflower	2003	Krichauff, Spear	yes	none	10 Apr	2.0	63	Sa	Sa
wheat	2003	Krichauff, Spear	yes	none	10 Apr	2.0	63	Sw	Sw
Pendleton-1	2001	Krichauff, Machete	yes	none	20 Mar	0.8	54	Sw	Sw
	2002	Zak	no	none	15 Mar	1.0	39	Sw	Sw
	2003	Krichauff, Machete	yes	none	9 Apr	2.0	64	Sw	Sw
Pendleton-2	2003	Krichauff, Machete	yes	none	9 Apr	2.0	64	Cp	Cp

[a] Where there are two experiments at one location, they are identified as sites 1 and 2, and abbreviated in the format Moro-1 and Moro-2.
[b] Where indicated, each experimental variety was planted, either with and without aldicarb applied in the seed furrow at 3.8 lb ai/acre.
[c] Soil temperature at the depth of seed placement at the time of planting.
[d] Crops grown one ("1-yr") and two years ("2-yr") before the current wheat crop: Ca = canola, Cp = chickpea, Sa = safflower, Sw = spring wheat, and Ww = winter wheat.

Additional experiments were performed at these and other locations, but are not reported in this paper. Also, additional plant growth, plant physiology, and nematode variables were measured for all experiments, and are also not reported in this paper. Detailed results for this research will be published in a series of technical papers.

Soil and plant sampling

Soil was collected to assess lesion nematode populations in every plot in each experiment. Preplant samples consisted of 15 to 20 cores (1-inch diam. by 4 inches deep) composited for each 110-ft^2 plot. Nematode extractions and identifications were performed at the Oregon State University (OSU) Nematode Testing Service (Corvallis) during 2001 and 2002, and at Western Laboratories (Parma, ID) during 2003. Numbers are reported as nematodes per pound of oven-dry soil. The process and level of detail for determining which *Pratylenchus* species was present differed each year. During 2001, the presence of each *Pratylenchus* species was assessed qualitatively in every plot in each experiment. Where mixtures of species occurred, the dominant and minor species were noted.

During 2002, subsamples from each plot in individual experiments were composited and proportions of *Pratylenchus* species were determined quantitatively for the experimental site rather than for individual plots, as was done during 2001. Species were not identified in samples sent to Western Labs for nematode extraction and quantification during 2003. For species identification, composite samples representing each site were sent to the Root Disease Testing Service in Adelaide, South Australia during 2003. DNA extracted from soil was used to identify *Pratylenchus* species, and to estimate numbers of each species in soil (Ophel-Keller and McKay, 2001).

Twenty root systems in each plot were collected between anthesis and grain filling. Lesion nematodes were enumerated and identified at the diagnostic laboratories, and numbers were normalized to equal units of root mass. Numbers are reported as nematodes per gram of fresh root tissue during 2001 and 2002 (OSU Lab) and on both a fresh-root and oven-dry-root tissue basis during 2003 (Western Lab).

Statistical analysis
Nematode and grain yield data were evaluated by analysis of variance. Similar experiments at each location were also evaluated across 3 years, using a 3-way randomized complete block design to incorporate the experimental year as a third variable. Regression analysis was used to examine relationships between grain yield and nematode numbers.

Results

Lesion nematode populations in soil before planting
Average lesion nematode populations for the 13 experimental sites varied from 24 to 2,202 nematodes/lb of soil (Table 2). These numbers represent populations that existed in soil before planting and before experimental treatments were applied at each site. More specifically, these site-averages are the average of populations detected in each of 30 to 36 plot areas that were marked with flags prior to planting each experiment. The populations were even more variable within individual plots. For instance, the average for the 0.1 acre (55 by 60 ft) site at the Hill Farm during 2001 was 1,404 nematodes/lb of soil (Table 2). The average number of lesion nematodes in each of the 30 plots (5.5 x 20 ft = 110 ft^2/plot) in that experiment ranged from 0 to 9,418 lesion nematodes/lb of soil (Table 2). Each plot average was derived from 15 to 20 soil cores collected and composited for each plot. The high level of variability (spatial heterogeneity) across very short distances is illustrated in Figure 1. Although not measured, the range of lesion nematode populations surely would have been much greater for individual soil cores than for the composite sample for each plot.

While populations of lesion nematodes were highly variable in individual plots for each experiment, the random assignment of treatments within each replicate of each experiment allowed adequate interpretation of results for these studies. There was only one instance in which the initial lesion nematode population was later determined to differ significantly among plots that were subsequently differentiated into individual variety and aldicarb combinations (data not presented). This occurred for the variety variable in the 2001 experiment at Moro-1. Preplant populations averaged 563 and 755 nematodes/lb ($P = 0.06$) for plots planted later to 'Krichauff' and 'Machete', respectively. We chose to retain results from that biased experiment, along with the 12 unbiased experiments, because the actual preplant lesion nematode population differences at Moro-1 did not appear to differ enough to be of biological significance. Greater preplant variability, albeit not statistically significant, was encountered at several other locations. Crop history affected average numbers of lesion nematodes at both sites where this variable could be evaluated. At Moro-2 during 2003, the average initial *Pratylenchus* population was higher ($P < 0.01$, $lsd_{0.05} = 89$) the block following spring wheat than following either chickpea or safflower (Table 2). At Pendleton during 2003, the average preplant population was higher where wheat was produced annually (Pendleton-1), than following chickpea (Pendleton-2).

168	1,936	73	1,755	2,764	532	205	77	1,677	82
2,318	1,564	50	223	18	4,873	132	577	9,418	318
1,232	336	0	41	173	23	5,800	4,882	732	150

Figure 1. Average numbers of lesion nematodes in 30 plots (each 5.5 by 20 ft) at the Hill Farm, Oregon, during March 2001. Numbers are the averages for 15 to 20 soil cores, collected and composited in each 110-ft^2 plot before treatments were applied at the time of planting. This map illustrates the natural variation in nematode numbers ("spatial heterogeneity") in an annually cropped commercial field. The experimental area (55 by 60 ft, or 0.1 acre) had an average population of 1,404 *Pratylenchus*/lb of soil, with a range of 0 to 9,418. The population range among individual cores within each composite would have been greater than among the composite samples, but individual cores were not measured before being composited for each plot.

Table 2. Lesion nematode population means and ranges in soils of individual 5.5- by 20-ft plots, and *Pratylenchus* species identifications, in 13 experiments in eastern Oregon; samples were collected during April and May 2001-2003, before planting spring wheat.

Location [a]	Year	Species [b]	Lesion nematode numbers	
			Mean [c]	Range
			no./lb	*no./lb*
Hill Farm	2001	Pn/Pt	1,404	0-9,418
	2002	90% Pn, 10% Pt	1,940	0-8,350
	2003	Pt/Pn	616	9-3,518
Moro-1	2001	Pn/Pt	429	0-2,700
	2002	67% Pn, 33% Pt	871	182-2,855
	2003	Pn	699	64-1,873
Moro-2 - chickpea	2003	nd	24	0-100
safflower	2003	nd	24	0-100
wheat	2003	Pn/Pt	450	64-1,564
Pendleton-1	2001	Pt/Pn	2,202	36-5,259
	2002	50% Pn, 50% Pt	1,198	114-4,795
	2003	Pt	963	73-2,264
Pendleton-2	2003	nd	496	9-4,418

[a] Where there were two experiments at one location, they were identified as sites 1 and 2, and abbreviated in the format Moro-1 and Moro-2.
[b] *Pratylenchus* species: Pn = *P. neglectus*, Pt = *P. thornei*, Pt/Pn or Pn/Pt indicate a species mixture in order of decreasing proportions for qualitative assessments in each plot during 2001. Proportions (% = percent) were determined quantitatively for each experimental area during 2002, and by DNA extraction and analysis for selected experiments during 2003. Species were not determined where designated by "nd".
[c] Samples were composed of 15-20 soil cores composited for each plot of the 30 or 36 plots in each experiment.

Lesion nematode identity

Ratios of *P. neglectus* to *P. thornei* varied markedly from location to location and from experiment to experiment (Table 2), including adjacent experiments with similar crop and tillage management histories. For instance, adjacent experimental sites during 2002 were established at each location but, for brevity, the second experiment at each location is not reported elsewhere in this paper. The ratios of *P. neglectus* to *P. thornei* in soil at the time of planting (April) at adjacent sites were reported as 40:56 and 90:10 at Hill Farm, 98:2 and 50:50 at Pendleton, and 60:40 and 67:33 at Moro. The second ratio stated for each location is the ratio reported in Table 2.

During 2003, the Root Disease Testing Lab in Australia used a highly specific DNA test to identify the lesion nematode species. DNA extracts indicated a strong dominance of *P. thornei* over *P. neglectus* at the Hill Farm (2,700 vs. 450/lb soil) and at Pendleton (5,500 vs. <400/lb soil), and a dominance of *P. neglectus* over *P. thornei* at Moro (4,100 vs. <400/lb soil). DNA values of <400/lb were below the detection error limit for the procedure. Therefore, all figures below 400/lb could indicate anywhere from 0 to nearly 400 lesion nematodes/lb. It was clear, however, that *P. thornei* was the dominant species at the Hill Farm and at Pendleton, and that *P. neglectus* was the dominant species at Moro. The reason(s) for a dominance of different *Pratylenchus* species at these locations is unknown.

Lesion nematode populations in wheat roots

The method of measuring *Pratylenchus* densities in roots differed through the course of this investigation. Numbers were based on the fresh weight of root tissue during 2001 and 2002, and on both a fresh- and dry-weight basis during 2003. During 2003 it was shown that the apparent average densities were approximately four times higher when evaluated on the basis of dry- compared to fresh-root weight. The average dry- to fresh-root ratio at each location varied from 3.8 at Moro to 4.3 at Pendleton. These differences reflected the maturity of roots at the time of sampling. Roots of succulent green plants would be expected to have high dry- vs. fresh-weight ratios. Roots of mature plants in dry soil would have ratios approaching 1.0. Accurate comparisons of *Pratylenchus* densities in roots at different locations, or among varieties that differ in maturation date, would require reporting root densities on a dry-weight basis. However, both systems provide information that allows accurate comparisons among treatments within individual experiments.

Nematode densities in roots were generally lower in 'Krichauff' than in 'Machete' or 'Spear', but this was statistically significant in only 3 of 13 experiments (Table 3). At Moro-2, the average density of *Pratylenchus* in oven-dry wheat roots was higher ($P < 0.01$) when the previous crop was wheat than either chickpea or safflower. In the wheat block at Moro-2, reproduction of *Pratylenchus* in roots was significantly lower in 'Krichauff' than 'Spear': 220 vs. 666/g root, $P < 0.01$, $lsd_{0.05} = 272$.

In contrast to the varietal effect, the aldicarb treatment significantly reduced densities of lesion nematodes in 12 of 13 experiments, including 2 experiments where the effect of aldicarb applications during 2001 was measured in the wheat crop produced without additional aldicarb during 2002.

Grain yield and test weight

Grain yields were low in these annual-crop experiments. This occurred because eastern Oregon experienced the third through fifth years of drought during 2001 through 2003.

Table 3. Lesion nematode densities (nematodes/g of root tissue) in mature spring wheat roots in 13 experiments at three locations in eastern Oregon, 2001-2003.

Location and site	Year	Reporting basis [a]	Krichauff control	Krichauff aldicarb	Machete or Spear [b] control	Machete or Spear [b] aldicarb	Significance [c] (P > F) variety	Significance [c] (P > F) aldicarb	Significance [c] (P > F) interaction
Hill Farm	2001	fresh	1,066	1	2,265	3	0.24	<0.01**	0.21
	2002 [d]	fresh	3,735	608	2,680	211	0.59	0.02*	0.81
	2003	fresh	151	7	644	85	0.13	0.07□	0.26
Moro-1	2001	fresh	1,761	8	2,521	53	0.54	0.02*	0.59
	2003	fresh	297	12	1,064	6	0.10□	<0.01**	0.09□
Moro-2 - chickpea	2003	fresh	14	1	24	3	0.44	0.02*	0.54
safflower	2003	fresh	17	1	18	0	0.95	<0.01**	0.76
wheat	2003	fresh	217	14	752	11	<0.01**	<0.01***	<0.01**
Pendleton-1	2001	fresh	15	0	902	4	0.32	0.25	0.27
	2002 [d]	fresh	269	174	522	38	0.45	<0.01**	0.04*
	2003	fresh	281	10	406	2	0.36	<0.01***	0.35
Pendleton-2	2003	fresh	31	4	187	2	0.07□	0.02*	0.07□
Hill Farm	2003	dry	1,010	43	4,660	635	0.12	0.07□	0.26
Moro-1	2003	dry	1,578	54	6,041	27	0.12	0.01**	0.11
Moro-2 - chickpea	2003	dry	67	2	125	13	0.41	0.03*	0.48
safflower	2003	dry	73	5	89	1	0.87	<0.01**	0.62
wheat	2003	dry	1,117	56	3,644	48	<0.01**	<0.01***	<0.01**
Pendleton-1	2003	dry	1,506	55	2,149	47	0.31	<0.01***	0.33
Pendleton-2	2003	dry	186	20	1,197	10	0.07□	0.02*	0.06□

[a] Nematode numbers were reported on the basis of fresh root weight or oven-dry root weight, depending on the testing laboratory. Dry root weights are more accurate when comparisons are made across sites, but fresh weights are acceptable when comparing treatments within individual experiments.

[b] 'Spear' was planted at Moro-2 in 2003, and 'Machete' was grown at all other sites.

[c] Comparisons were accepted as significant at confidence intervals of 90 (□), 95 (*), 99 (**), or 99.9 (***) percent.

[d] During 2002 'Zak' spring wheat was planted uniformly over the 2001 sites, and aldicarb was not applied with the seed. Samples were collected in accordance with treatments applied during 2001, i.e., where 'Machete' and 'Krichauff' had been grown with or without aldicarb. This treatment and sampling protocol was designed to evaluate carry-over effects from treatments applied the previous year.

During the years of these experiments, precipitation at Moro was 44, 24, and 17 percent below the 20-year mean annual precipitation of 11.1 inches. Spring rainfall (March through June) at Moro was 34, 35, and 41 percent below the 20-year mean of 3.5 inches. Precipitation at Pendleton was 5, 25, and 10 percent below the 20-year mean annual precipitation of 17.4 inches. During the spring months (March through June), rainfall was 12, 25, and 58 percent below the 20-year mean of 6.6 inches.

Yields of 'Krichauff' were significantly higher than 'Machete' and 'Spear' in 9 of 11 experiments (Table 4). Yield differentials for these varieties were generally greater at sites with high *Pratylenchus* populations, and lower at sites with low populations. Yields for the susceptible varieties in five experiments were 20-70 percent lower than for the moderately resistant variety. In 2002, yields of 'Zak' at all three sites did not differ in response to plantings of either 'Krichauff' or 'Machete' during 2001. For these three locations, during years of drought, there was no carry-over effect from the different populations of lesion nematodes resulting from the production of a moderately tolerant or a susceptible variety the previous year.

Statistically significant (99 percent confidence interval; i.e., $P < 0.01$) differences in yield were detected when data from each site were pooled for all 3 years. 'Machete' yielded 52, 36, and 16 percent less than 'Krichauff' at the Hill Farm (8.0 vs. 16.8 bu/acre), Pendleton (16.4 vs. 25.7 bu/acre), and Moro (16.1 vs. 19.1 bu/acre), respectively. In two seed-increase blocks on summer fallow sites with low *Pratylenchus* populations at Pendleton during 2000 and 2001 (data not presented), the average yield for 'Machete' (28.4 bu/acre) was 16 percent lower than for 'Krichauff' (33.7 bu/acre). The yield advantage for 'Krichauff' over 'Machete' was clearly more pronounced at sites where lesion nematode populations limited grain yield.

Aldicarb was applied in 10 of the 13 experiments reported in this paper. Aldicarb application was associated with significantly improved grain yield in all five experiments where initial *Pratylenchus* populations exceeded 400/lb of soil at the two higher rainfall sites, the Hill Farm and Pendleton (Table 4). Grain yields at those sites were also higher for 'Zak' planted into plots treated with aldicarb during 2001, compared to 'Zak' grown in the 2001 control treatments. When data for all 3 years was pooled, aldicarb improved average wheat yield at the Hill Farm 92 percent compared to the untreated control (16.3 vs. 8.5 bu/acre; $P < 0.01$). At Pendleton, aldicarb improved the 3-year average yield by 67 percent compared to the untreated control (26.3 vs. 15.8 bu/acre; $P < 0.01$). During 2001, yield improvement with aldicarb at the Hill Farm was significantly higher for 'Krichauff' (59 percent) than for 'Machete' (22 percent), suggesting a higher potential for responsiveness when genetic resistance and nematicide are both present.

Aldicarb did not improve yield in any of the experiments at Moro, the driest location in this study. Moreover, aldicarb was associated with a significant reduction in yield in two of the six experiments at Moro. When data at Moro-1 was averaged over 3 years, aldicarb reduced yield by 7 percent compared to the untreated control (17.0 vs. 18.3 bu/acre; $P = 0.03$).

Aldicarb application was associated with significantly greater grain test weight in four of seven experiments at the two higher rainfall sites, the Hill Farm and Pendleton (data not presented). Grain yields at those sites during 2002 were also 0.2 to 0.9 lb/bu higher for

Table 4. Grain yields (bu/acre) for spring wheat in 13 experiments at three locations in eastern Oregon in 2001-2003.

Location and site	Year	Krichauff		Machete or Spear [a]		Significance [b] (P > F)		
		control	aldicarb	control	aldicarb	variety	aldicarb	interaction
Hill Farm	2001	21.4	34.0	10.3	12.6	<0.01***	<0.01**	0.02*
	2002 [c]	12.5	14.6	12.7	16.5	0.81	0.85	0.81
	2003	10.4	22.6	5.4	13.3	<0.01***	<0.01***	0.05*
Moro-1	2001	7.4	8.0	5.7	5.1	0.02*	0.97	0.43
	2002 [c]	25.1	23.9	22.0	26.3	0.78	0.33	0.11
	2003	21.5	19.4	16.9	16.7	<0.01***	0.04*	0.14
Moro-2 - chickpea	2003	23.0	22.3	20.3	20.9	<0.01**	0.93	0.12
safflower	2003	18.6	15.4	16.5	16.8	0.12	<0.01***	<0.01**
wheat	2003	22.7	20.2	19.1	20.7	<0.01**	0.40	<0.01***
Pendleton-1	2001	22.7	39.2	9.9	17.0	<0.01**	<0.01**	0.10□
	2002 [c]	37.0	40.0	36.5	36.9	0.53	0.67	0.58
	2003	15.9	24.5	7.8	17.3	<0.01***	<0.01***	0.46
Pendleton-2	2003	22.2	34.0	14.1	27.6	<0.01***	<0.01***	0.22

[a] 'Spear' was planted at Moro-2 in 2003, and 'Machete' was planted at all other sites.

[b] Comparisons were accepted as significant at confidence intervals of 90 (□), 95 (*), 99 (**), or 99.9 (***) percent.

[c] During 2002 'Zak' spring wheat was planted uniformly over the 2001 sites, and aldicarb was not applied with the seed. Samples were collected in accordance with treatments applied during 2001, i.e., where 'Machete' and 'Krichauff' were grown with or without aldicarb. This treatment and sampling protocol was designed to evaluate carry-over effects from treatments applied the previous year.

'Zak' planted into plots treated with aldicarb during 2001, compared to 'Zak' growing in the 2001 control treatments. Aldicarb was consistently associated ($P = 0.001$ to $P = 0.09$) with reduced test weight in each of the six experiments at Moro.

Relationships between grain yield and lesion nematodes

At sites where initial *Pratylenchus* populations in soil were 400/lb of soil, or higher, grain yield was significantly negatively correlated with the initial soil population of *Pratylenchus* in 7 of 11 experiments, and with *Pratylenchus* populations in roots in 3 of 11 experiments. At high *Pratylenchus* populations, significant negative correlations between yield and *Pratylenchus* occurred each year at the lowest rainfall site (Moro), and in only one of four experiments at the highest rainfall site (Pendleton). Yield stability with increasing *Pratylenchus* population was generally higher for the more resistant and tolerant variety ('Krichauff'), compared to the more susceptible and intolerant varieties ('Machete' and 'Spear').

At the Hill Farm, during 2001, grain yield in control plots was negatively correlated with the preplant population of *Pratylenchus* (Fig. 2). Wheat yield was reduced by approximately 70 percent (17 bu/acre) as the *Pratylenchus* population increased. During 2003, the yield for the *Pratylenchus*-susceptible variety, 'Machete', but not the moderately resistant variety, 'Krichauff', was negatively correlated with preplant populations of *Pratylenchus* (Fig. 3). Yield of 'Machete' was reduced by approximately 60 percent as the *Pratylenchus* population increased. Density of *Pratylenchus* in mature roots was also negatively correlated with grain yield (Fig. 4).

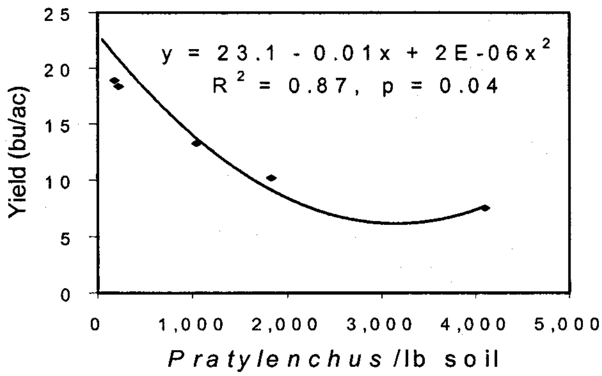

Figure 2. Relationship between preplant numbers of a mixed population of *Pratylenchus neglectus* and *P. thornei* and grain yield for two spring wheat varieties, combined, for control plots (not treated with aldicarb) at the Hill Farm, Oregon, in 2001.

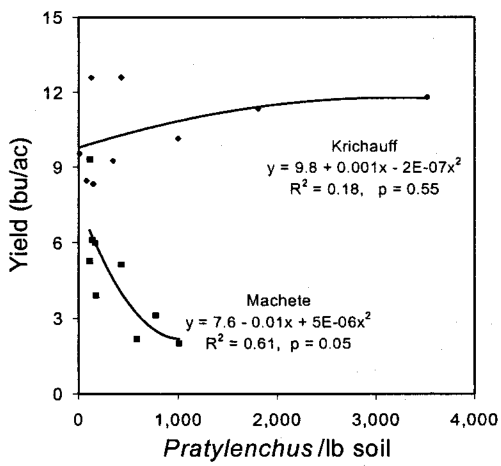

Figure 3. Relationship between preplant numbers of a mixed population of *Pratylenchus neglectus* and *P. thornei* and grain yield for two spring wheat varieties in control plots (not treated with aldicarb) at the Hill Farm, Oregon, in 2003.

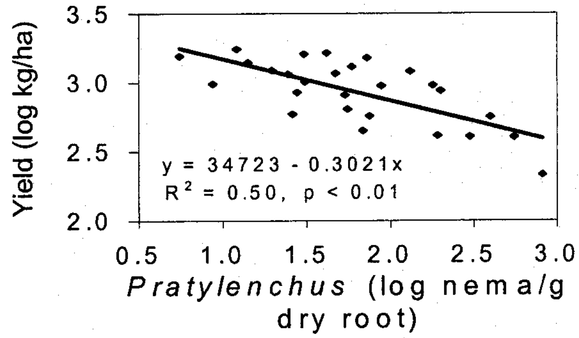

Figure 4. Relationship between grain yield and *Pratylenchus* numbers in mature roots of for two spring wheat varieties, combined, at the Hill Farm, Oregon, in 2003.

Yield was also negatively correlated with preplant populations of *Pratylenchus* in control plots at Moro-1 during 2001 (Fig. 5). Although yields at that site were very low, the yield was reduced by approximately 60 percent as the *Pratylenchus* population increased. Yield was also negatively correlated with initial populations of *Pratylenchus* when 'Zak' was planted during 2002 (Fig. 6). Wheat yield was reduced by approximately 30 percent as the *Pratylenchus* population increased. During 2003 at Moro-1, the yield of 'Machete', but not 'Krichauff', dropped as the *Pratylenchus* population increased (Fig. 7). In the wheat block at Moro-2, the yield of 'Spear', but not 'Krichauff', declined with increasing *Pratylenchus* population (Fig. 8).

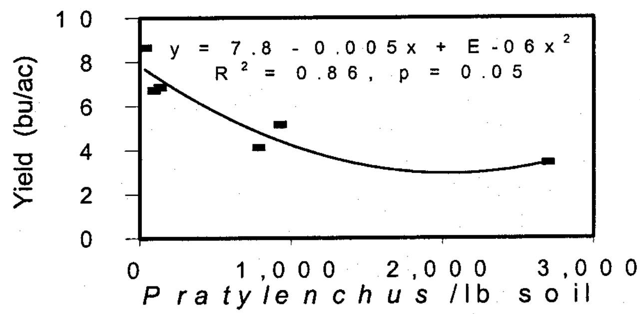

Figure 5. Relationship between preplant numbers of a mixed population of *Pratylenchus neglectus* and *P. thornei* and grain yield for two spring wheat varieties, combined, in control plots (not treated with aldicarb) at Moro, Oregon, in 2001.

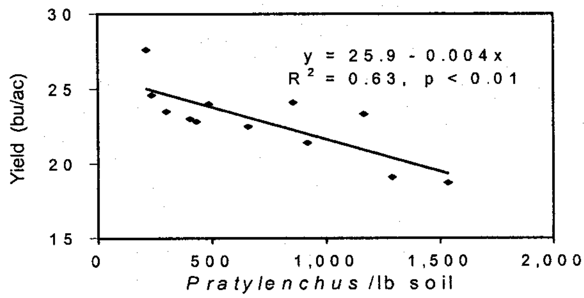

Figure 6. Relationship between preplant numbers of a mixed population of *Pratylenchus neglectus* and *P. thornei* and grain yield during 2002 in 'Zak' spring wheat planted uniformly over the 2001 Moro-1 site, Oregon.

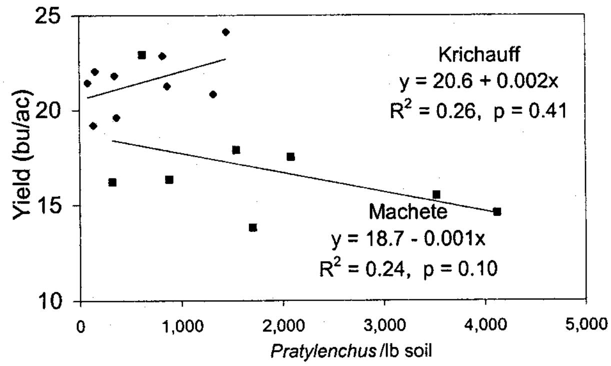

Figure 7. Relationship between preplant numbers of a mixed population of *Pratylenchus neglectus* and *P. thornei* and grain yield for two varieties of spring wheat in control plots (not treated with aldicarb) at Moro, Oregon, in 2003.

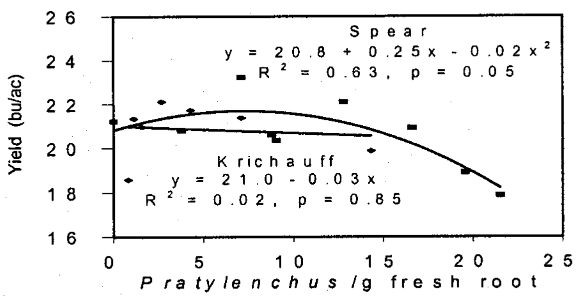

Figure 8. Relationship between grain yield and number of *Pratylenchus* in roots of aldicarb-treated 'Krichauff' and 'Spear' wheat in the recrop "wheat block" at Moro-2, Oregon, in 2003.

Grain yield in control plots at Pendleton during 2001 was negatively correlated with the preplant population of *Pratylenchus* ($R^2 = 0.46$, $P = 0.05$). During 2002, the *Pratylenchus* population in soil and in roots of 'Zak' were significantly reduced where aldicarb had been applied during 2001, but the grain yield and test weight did not differ among treatments applied during 2001, and were not correlated with initial *Pratylenchus* population in soil or density in wheat roots. During 2003, yields at Pendleton-1 and Pendleton-2 were not correlated with the initial populations of *Pratylenchus* in soil but were negatively correlated with the density of *Pratylenchus* in roots (Figs. 9 and 10). In each case, 'Machete' was more sensitive than 'Krichauff' to increasing density of *Pratylenchus* in roots.

When evaluated across 3 years at Pendleton-1, there was a weak negative correlation (R^2 = 0.13, $P = 0.01$) between yield and initial soil population of *Pratylenchus* in 'Machete' plots but no significant correlation in 'Krichauff' plots. There was also a weak negative correlation ($R^2 = 0.16$, $P < 0.01$) between 'Machete' yield and density of *Pratylenchus* in roots, and a weaker negative correlation when data for both varieties were combined (R^2 = 0.09, $P < 0.01$).

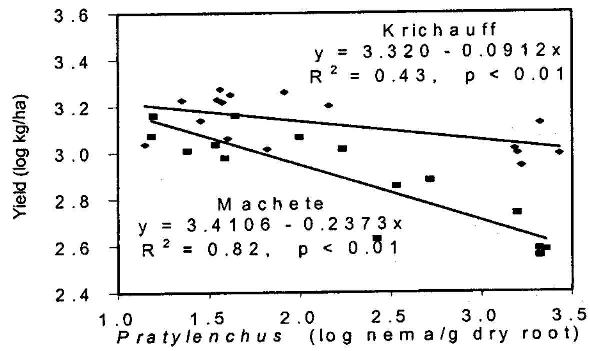

Figure 9. Relationship between grain yield and *Pratylenchus* numbers in mature wheat roots at Pendleton-1, Oregon, in 2003.

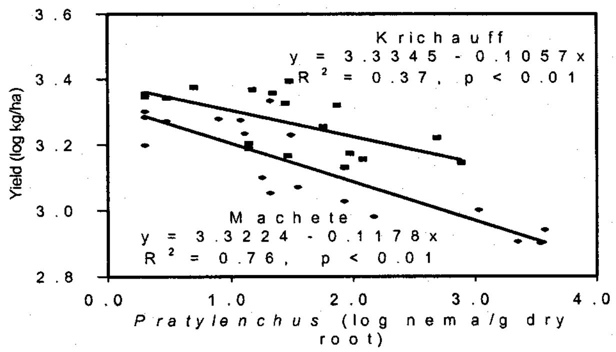

Figure 10. Relationship between grain yield and *Pratylenchus* numbers in mature wheat roots at Pendleton-2, Oregon, in 2003.

Diseases and insects

Root diseases were caused by a complex of Rhizoctonia root rot, take-all, Fusarium crown rot, and Pythium root rot. Foliar diseases did not occur. Details are being published elsewhere (Smiley et al. 2004b). Briefly, disease incidence and severity generally did not differ significantly among varieties or aldicarb treatments in any year. During 2001, Hessian fly was more prevalent at Hill Farm and Pendleton (91 and 90 percent of plants had one or more puparia) than at Moro (39 percent of plants). The level of infestation was generally unaffected by treatment but was less in aldicarb-treated than control plots (85 vs. 98 percent, $P = 0.02$) at Hill Farm and less in 'Krichauff' than 'Machete' (23 and 55 percent, $P < 0.01$) at Moro. Hessian fly was not prevalent and was not quantified during 2002 and 2003.

Discussion

Research reported here and in technical manuscripts (Smiley et al. 2004a, Smiley et al. 2004b) has shown that *P. thornei* and *P. neglectus* 1) occur in high numbers in many dryland annually cropped fields, 2) injure wheat roots, 3) increase late-season plant stress as reflected by greater canopy temperature, 4) reduce plant biomass production by reducing both plant height and tillering, 5) reduce grain yield, and 6) reduce grain quality by reducing test weight and kernel weight. *P. thornei* and *P. neglectus* must therefore be included among the pathogens and insects known to limit productivity of spring wheat in annual-crop systems in the PNW (Smiley 1996, Paulitz et al. 2002, Smiley et al. 2004b). Economic damage to dryland field crops by *P. thornei* or *P. neglectus* had not previously been demonstrated in the PNW.

Application of aldicarb was repeatedly associated with reduced density of lesion nematodes in roots and with higher grain yield and quality. We demonstrated yield losses as high as 70 percent, and consistently inverse associations between grain yield and *Pratylenchus* populations. The *Pratylenchus*-resistant variety greatly limited *Pratylenchus* reproduction in roots. Grain yield was generally more stable for the resistant than the susceptible varieties as *Pratylenchus* populations increased within individual experiments. The yield of 'Machete', a *Pratylenchus*-sensitive variety, was inversely correlated with a *P. thornei*-dominated species mixture at initial *Pratylenchus* populations as low as 400/lb of soil.

Application of aldicarb improved grain yield in all seven experiments (five at $P < 0.01$), conducted over 3 years at two locations in Oregon, where *Pratylenchus* populations were high and soil water availability was not the most limiting factor for crop production, i.e., the Hill Farm and Pendleton. Aldicarb did not increase productivity of wheat in four experiments with high populations of *Pratylenchus* at a location with very low rainfall (Moro), or in two experiments with low *Pratylenchus* populations at Moro. Interpretation of results was confounded by likely differences in amounts of available soil water and a dominance of *P. thornei* at the Hill

Farm and at Pendleton, and of *P. neglectus* at Moro. Results presented in this paper provide evidence only that *P. thornei* reduces wheat yields. However, in other experiments (not reported here) conducted in irrigated fields in Union County, Oregon, we determined that yields of susceptible spring wheat varieties were also negatively correlated with increasing populations of *P. neglectus*. Therefore, both species are now known to be capable of causing economic damage to spring wheat in annual cropping systems in Oregon.

During a very dry year (2003) at Moro, *P. neglectus* density in roots of 'Spear', a sensitive wheat variety, was associated with declining grain yield as the density exceeded 60/g root (dry-weight basis; comparable to 15/g on a fresh-weight basis). Very low densities of *P. neglectus* in roots appear to be associated with declining yield at sites severely restricted in availability of soil water near the end of the growing season. However, inverse correlation of grain yield and *Pratylenchus* density in roots was unpredictable in this study, and was apparently affected by other unknown factors. As such, work reported here was insufficient for developing damage thresholds for *Pratylenchus* species in the PNW.

Pratylenchus species have many hosts. *P. neglectus* attacks all cereals, as well as rotational crops such as grain legumes, pasture legumes and grasses, oilseeds (Vanstone et al. 1994, Griffin and Jensen 1997), and many broadleaf and grass weeds (Vanstone and Russ 2001a, 2001b). However, nematode multiplication differs greatly in roots of various crop species and among varieties within crop species (Vanstone et al. 1998). In Australia, Taylor et al. (2000) concluded that wheat was a good host for *P. neglectus*, whereas barley, oats, and durum wheat were moderate hosts, and triticale was a poor host. Hollaway et al. (2000) reported that most commercial wheat varieties grown in southeast Australia were susceptible to *P. thornei*, that barley varieties were resistant or moderately resistant, that canola was moderately resistant, and that lentil, field pea, and flax were resistant. In studies reported in this paper, *P. thornei* populations were reduced after 2 years of chickpea at Pendleton, and *P. neglectus* populations at Moro were reduced after 2 consecutive years of chickpea or safflower, compared to spring wheat. Unfortunately, these crops also differ in rate of water extraction, so that the true impact of reduced *P. neglectus* populations could not be determined at Moro where water was the most important yield-limiting factor.

Identification of *Pratylenchus* species is usually based on microscopic evaluations. Only a few visible characteristics differentiate *P. neglectus* from *P. thornei*, and no characteristics are easily distinguished. The differentiating characteristics include the number of annules (slight ridges) on the lip and a minor difference in the position of the vulva relative to the overall length of the female body. The difficulty in seeing and measuring these differences, even with a high-power microscope, makes exacting distinctions among species exceedingly difficult. We currently believe that the most accurate diagnostic results are achieved by using traditional extraction and quantification procedures to determine *Pratylenchus* populations in soil and roots, and to use molecular DNA extraction procedures to identify the *Pratylenchus* species that are present in those samples. This is the approach we began using in our research during 2003. Although we sent soil and/or DNA extracts to Australia for identification of species, we are currently adapting molecular procedures that will enable us to make these determinations in our laboratory at Pendleton.

The high level of spatial heterogeneity for lesion nematodes in soil made it difficult to determine relationships between nematode populations and grain yield. This same challenge will occur when developing strategies for sampling commercial fields. Many samples are required to assure that "hot spots" in fields do not create excess bias. Likewise, it is important to collect separate composite samples that accurately represent known differences in each field, as in topography, soil, or drainage.

Aldicarb is not registered for commercial use in wheat crops, and there is a zero tolerance for residual decomposition products of this nematicide in wheat grain. Therefore, all grain produced in these experiments was destroyed to prevent unintentional entry into shipping and processing channels for food products. It is, therefore, not possible to apply this nematicide to wheat in commercial production. Aldicarb and other insecticides and nematicides are registered for controlling pests in higher-value irrigated crops such as potato. However, under dryland conditions, deployment of genetic resistance is the only practical and affordable strategy for reducing lesion nematode damage in annually cropped dryland fields. While one moderately resistant variety was shown to be of value during these studies, more promising germplasm is now being identified in wheat breeding programs in other countries. We recently acquired the most resistant and tolerant wheat germplasm identified in international development programs, and are currently evaluating the new lines. If they respond as described, they will be identified as potential breeding parents for use in PNW wheat breeding programs.

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LONG-TERM EXPERIMENTS AT CBARC-PENDLETON, 2002 AND 2003

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Abstract

The Columbia Basin Agricultural Research Center (CBARC) is home to the oldest experiments in the Pacific Northwest (PNW). The perennial grassland, continuous cereal, and residue management experiments were initiated 1931, and the tillage-fertility, wheat-pea rotation, and no-till wheat were initiated in 1940, 1963, and 1982. This article summarizes the results obtained in 2002 and 2003. The *perennial grassland* serves as a base-line for comparisons with other systems. *Continuous cereal*: in both conventional and no-till cropping systems, spring barley produced the highest yield followed by winter wheat and then spring wheat. In winter wheat cropping systems, there was no difference in yield between conventional and no-till systems. Spring wheat and spring barley produced higher yields under conventional tillage than under no-till cropping system. *Crop residue*: high yields were obtained when manure or nitrogen (N) was applied. Field burning without N application resulted in the lowest yields. *Wheat-pea rotation*: for wheat, highest yields were produced when plots were plowed in the fall or spring. The lowest yield was produced in the no-till system where downy brome infestation was significantly high. For peas, the highest yield was produced under the no-till system and the lowest yield was produced when plots were plowed in the fall. *Tillage fertility*: increasing N rates up to 120 lb/acre increased yield through greater numbers of heads/ft^2. The highest yield was produced under the plowed plots, which had a greater number of heads/ft^2 than the disked and swept plots. The sweep treatment produced the lowest yield, probably because of a high downy brome infestation. *No-till wheat*: in both no-till treatments, grain yields increased with increasing N fertilization up to 80 lbs/acre, then declined. There was little difference between the older set of plots (A) and the newer set of plots (B). Grain yields in the conventional tillage plots, with the same N fertilization rates, were consistently greater. Residue yields showed similar trends as the grain yields.

Introduction

Long-term research guides future agricultural development by identifying the effects of crop rotation, variety development, fertilizer use, aerial and surface contamination, and organic amendments on soil productivity and other beneficial soil properties. Comprehension and evaluation of many changes often requires 10-20 years to identify and quantify. Soil microflora and soil-borne plant pathogens require from 2 to 8 years in a new cropping sequence or tillage system to reach a stable equilibrium. To this end, long-term experimentation is required to understand interactions among soil, water, and plant factors for both agronomic and agricultural policy decisions. The oldest experiments in the PNW are at CBARC, Pendleton, in the intermediate rainfall zone (Table 1). Below is a brief description of these experiments and the results obtained in the 2002 and 2003 crop years. The treatments have changed over the years and the descriptions below refer to current procedures. Detailed descriptions of the protocols and how they have changed over time have been compiled into a database located on our network server. A detailed progress report on these trials is planned for later this year and will contain both detailed descriptions of each experiment and more extensive analysis of the trials over time. During 2003, data collected from 1998 through 2003 were reviewed and data summaries for all years of all experiments were prepared.

Description of Experiments

Table 1. Long-term experiments at CBARC, Pendleton, Oregon.

Experiment	Treatments	Year initiated
Perennial grassland	None	1931
Continuous cereal	Fertility, tillage	1931
Residue management	N, manure, burning, pea vine	1931
Tillage-fertility	Tillage, fertility	1940
Wheat-pea	Tillage, fertility	1963
No-till wheat	N, summer fallow	1982

Perennial grassland

The perennial grassland site (150 ft wide by 360 ft long) contains no experimental variables, but has been maintained since 1931. The site is intended to approximate a near-virgin grassland and serves as a base-line for evaluating changes in other cropping systems. It is periodically reseeded with introduced grass selections, occasionally fertilized, and infrequently irrigated. The dominant grass species are bluebunch wheatgrass (*Agropyron spicatum var. 'Secar'*) with lesser amounts of Idaho fescue (*Festuca idahoensis var. 'Joseph'*). Weeds, particularly witchgrass (*Panicum capillare*), common mallow (*Malva neglecta*), and downy brome (*Bromus tectorum*), are controlled as needed. This site received limited grazing from 1931 to 1985. It has not been grazed since, but vegetation is sometimes clipped during or after summer growth. Above-ground productivity has been measured since 1996. This area has recently gone through a renovation process involving repeat applications of glyphosate to kill existing species, very shallow tillage, and reseeding with a John Deere (JD) power-till drill.

Continuous cereal

The objectives of the various continuous cereal monocultures have varied over the years; however, the current objective is to determine the effects of annual mono-cropping on crop yield and soil productivity. Annual monoculture plots of winter and spring wheat and spring barley, using plow (inversion) tillage are maintained. In each plot there are fertilized and unfertilized blocks. Treatment histories for the tilled plots are shown in Table 2. A no-till (direct seeded) annual winter and spring wheat and spring barley companion plot was established in 1998 and the treatments are shown in Table 3. The plots are not replicated. The most practical, generally recommended methods and equipment available to growers are used. In 2002 and 2003, a JD 8300 double disk drill on 6.8-inch spacing was used to seed all conventional till monocultures. In 2002, a JD 1560 disk drill on 7.5-inch spacing and a Conservapak (CP) hoe drill on 12-inch spacing were used to seed no-till spring barley and no-till winter wheat plots. No-till spring wheat plots in 2002 were seeded with the JD 1560 drill. In 2003, all no-till plots were seeded with the CP drill. In both 2002 and 2003, all spring barley plots were seeded to 'Baronesse'. Spring wheat plots were seeded to 'Alpowa' in 2002 and 'Zak' in 2003. All winter wheat plots were seeded to 'Stephens' in 2002. In 2003, no-till winter wheat was seeded to 'Clearfirst' and conventional till winter wheat was seeded to 'Stephens'. In 2002 and 2003, all fertilized monocultures received the equivalent of 100 lbs/acre of 16-20-0-14 (N, P, K, S). In conventional plots this was applied as a plowdown dry product and in no-till plots this was drill applied either as a liquid or as a dry product. In conventional till monocultures the balance of the nitrogen (N) was applied as plowdown urea and in no-till monocultures the balance of the N was drill applied as urea granules or urea-ammonium nitrate solution.

Table 2. Treatment history of the tilled continuous cereal monocultures.

Period	Crop grown	Variables	N Application
1932-1950	Winter wheat	Fertilizer rate and type	0-126
1951-1958	Winter wheat	None	0
1959-1976	Winter wheat	None	70
1977-1992	Winter wheat	None	80
1993-2003	Winter wheat	Fertility	0,80
1932-1953	Spring wheat	Fertilizer rate and type	0-94
1954-1958	Spring wheat	None	0
1959-1976	Spring wheat	None	74
1977-1992	Spring wheat	None	80
1993-2003	Spring wheat	Fertility	0,80
1982-1994	Spring barley	None	80
1994-2003	Spring barley	Fertility	0,80

Table 3. Treatment history of the direct-seeded continuous cereal monocultures.

Period	Crop grown	Variable	N Application
1998-2003	Spring barley Spring wheat Winter wheat	N Rate N Rate N Rate	0, 90 0, 90 0, 100

Crop residue management

The Crop Residue experiment is the most comprehensive of the long-term experiments at Pendleton. The objective of the experiment is to determine the effects of N application, burning, and pea vine and manure application on soil properties and productivity in a conventional moldboard plow, winter wheat-summer fallow production system. Treatment history is shown in Table 4. The experimental design is an ordered block consisting of nine treatments (10 originally) and two replications. The experiment contains duplicate sets of treatments that are offset by 1 year so that data can be obtained annually. In 2002 and 2003, plots were seeded to 'Stephens' using a JD 8300 double disk drill on 6.8-inch spacing. Inorganic N was supplied as urea ammonium nitrate applied preplant using a shank applicator.

Table 4. Treatment history of the residue management (CR) experiment.

		1931-1966		1967-1978		1979 to present	
Trt No.	Organic-N addition	RT[a]	N[b]	RT	N	RT	N
1	---[c]	--	--	--	--	--	--
2	---	FD	0	NB	40	SB	40
3	---	SD	0	NB	80	SB	80
4	---	NB	30	NB	40	NB	40
5	---	NB	30	NB	80	NB	80
6	---	FB	0	FB	0	FB	0
7	---	SB	0	SB	0	SB	0
8	Manure[d]	NB	0	NB	0	NB	0
9	Pea vines[e]	NB	0	NB	0	NB	0
10	---	NB	0	NB	0	NB	0

[a] Residue treatment: FD = fall disk, SD = spring disk, NB = no burn, FB = fall burn, SB = spring burn.
[b] N rate (lb/acre/crop); applied early October of crop year.
[c] 1 ton/acre/crop field weight alfalfa hay applied to plot 11 1939-1949 1-3 days prior to plowing
[d] Manure = (10 tons/acre/crop wet wt; 47.5 percent dry matter; 1,404 lb C and 113 lb N/acre/crop; applied in April or May of plow year (1-3 days prior to plowing).
[e] Pea vines = (1 ton/acre/crop field weight; 88.4 percent dry matter; 733 lb C and 34 lb N/acre/crop; applied 1-3 days prior to plowing.

Tillage fertility

The objective of the Tillage Fertility experiment is to determine the effects of three tillage regimes and six N rates on soil properties and productivity in a tilled winter wheat-summer fallow production system. Treatments are shown in Table 5. The experimental design is a randomized block split-plot, with three replications. Main plots consist of three primary tillage systems (moldboard plow, offset disk, and subsurface sweep) and subplots of six fertility levels. In 2002 and 2003, plots were seeded to 'Stephens' with a JD 8300 double disk drill on 6.8-inch spacing.

Table 5. Treatment history of the tillage-fertility (TF) experiment.

Primary treatment (tillage)		Tillage depth	Average residue cover
Symbol	Type	(inches)	at Seeding (%)
MP	Moldboard plow	9	7
DI	Offset disk	6	34
SW	Subsurface Sweep	6	43

Sub-treatment (fertility)		N Rate (lb/acre/crop)			
No.	Sulfur application	1941-1952	1953-1962	1963-1988	1989-present
1	No	0	0	40	0
2	Yes	10	30	40	40
3	No	0	0	80	80
4	Yes	10	30	80	80
5	Yes	10	30	120	120
6	Yes	10	30	160	160

N applied 7-14 days prior to seeding as ammonium sulfate from 1941 to 1962, ammonium nitrate from 1963 to 1988, and urea-ammonium nitrate since 1989. N broadcast from 1941 to 1988, and banded 6 inches deep with 10-inch row spacing since 1989.

Wheat/pea

The wheat/pea experiment was established in 1963. The objective of the experiment is to determine effects of four different tillage regimes on soil properties and productivity in a wheat/legume annual crop rotation. Treatments are shown in Table 6. Crop rotation is winter wheat/dry spring pea and the experimental design is a randomized block with four replications. Each replication contains eight plots (four treatments duplicated within each replication). Duplicate treatments, offset by 1 year, ensure yearly data collection for both wheat and peas. In 2002 and 2003, all tilled plots were seeded using a JD 8300 double disk drill on 6.8-inch spacing. In 2003, no-till peas were sown using a Great Plains double disk drill on 10-inch spacing and no-till wheat was sown using a Noble split packer drill on 10-inch spacing. In 2002 all no-till plots were sown using a JD 1560 disk drill on 7.5-inch spacing. In both years, 'Stephens' winter wheat and 'Universal' dry pea were sown. All fertilizer was applied as pre-plant shank-applied liquid fertilizer. Tilled winter wheat plots received 80 lb N/acre and no-till winter wheat plots received 90 lb N/acre. All pea plots received 16 lb N/acre. Both peas and wheat receive P and S along with the N application.

No-till wheat (summer fallow)

This experiment was established in 1982 and last revised in 1997. The modifications made in 1997 offered an opportunity to make comparisons between new and established direct seed systems. Since the fall of 1997, the overall experiment has consisted of three different components: (1) a 20-year-old no-till management system, with five N levels; (2) new treatments incorporating a 5-year-old no-till management system, also with five N levels; and (3) another 5-year-old addition utilizing conventional tillage, with only two N levels. The three main objectives of these components are: (1) to determine if any significant changes in soil quality occurred in the older portion of the experiment after 20 years of direct seeding (NT); (2) to evaluate the rate of change in selected soil parameters with adoption of NT; and (3) to identify problems that may occur during a transition from conventional tillage to direct seed and to mitigate those adverse changes. The experiment was designed so that half the plots are cropped and half are fallow in any given year, with the subsequent year cropping system reversed, thus allowing yield data to be taken every year. The experiment (with the exception of the tilled component) is strictly without tillage, other than during seeding and stubble flailing. Plots are usually seeded in

Table 6. Current treatments of the wheat/pea (WP) experiment.

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

Table 7. No-till summer fallow experiment treatments.

Component	Year of initiation	System	N rates (lbs N/acre)
Old no-till(A)	1982	No-till	0,40,80,120,160
New no-till(B)	1997	No-till	0,40,80,120,160
Conventional till(C)	1997	ConventionaltTill	0,120

mid-October with 'Stephens' wheat using a modified Noble no-till drill using HZ openers on 10-inch centers. Seeding rate is normally in the range of 105 to 110 lbs seed/acre and N is added as Solution-32, with P and S also banded at seeding (Table 7). Herbicides are used to control weeds in both fallow and crop no-till plots and the conventionally tilled plots are rod weeded.

Results and Discussion

Precipitation and temperature

The Pendleton station received 82 percent and 98 percent of 71- and 72-year average crop-year precipitation in 2002 and 2003, respectively (Table 8). Winter precipitation amounted to 81 percent and 106 percent of 71- and 72-year average winter precipitation in 2002 and 2003, respectively. Spring precipitation was 83 percent of the 71-year average in 2002 and 85 percent of the 72-year average in 2003. Based on growing degree days (GDD), the crop-year and winter temperatures were slightly warmer than the 71- and 72-year average in both years (Table 8.). The spring was cooler than the 71-year average in 2002 but warmer than the 72-year average in 2003.

Table 8. Precipitation and growing degree days in the 2002 and 2003 crop-years.

	Time period			
	2002	71-year	2003	72-year
Fallow year precipitation (in)	16.3(2001)	16.5	13.0(2002)	16.5
Crop-year precipitation (in) Sept 1-June 30	12.8	15.7	15.4	15.6
Two-year precipitation (in)	29.1(2001-2002)	32.2	28.4(2002-2003)	32.1
Winter season precipitation (in) Sept 1-Feb 28	7.9	9.8	10.4	9.8
Spring season precipitation (in) March 1-June 30	4.9	5.9	5.0	5.9
Crop-year GDD Sept 1-June 30	2,692	2,643	2,808	2,647
Winter season GDD Sept 1-Feb 28	1,340	1,236	1,284	1,237
Spring season GDD March 1-June 30	1,351	1,407	1,523	1,410

Managed perennial grassland

This perennial grassland serves as a base-line for comparisons with other systems. Usually scientists sample the area to obtain data to answer specific questions they are investigating at other sites. There is no systematic data collection from the grassland. Limited data are available since 1996 when above-ground biomass of the grasses was measured. Soil data are collected every 5 and 10 years to determine soil carbon status of the grassland. This area has recently gone through a renovation process involving repeat applications of glyphosate to kill existing species, very shallow tillage, and reseeding with a JD power-till drill. Following renovation, protocols have been established for continuing biomass measurement and soil data collection.

Continuous cereal

Plant stand

Plant counts, to determine plant stand, were started in 2003 (Table 11). In that year only about 50 percent of the target stand was achieved in conventionally tilled winter wheat plots compared to about 80 percent in the no-till winter wheat. The conventional winter wheat was "dusted in" because 2002 fall rains fell late. The first significant rain was on October 29th with below normal precipitation during November of 2002. Dusting seed in usually results in poor plant stands because seeds are either placed too deep or between loose clods where conditions are not conducive for maximum water uptake (imbibition). In contrast, direct seeded (no-till) plots did not have these problems and higher plant stands were achieved. In both conventional and no-till winter wheat plots plant stands were higher in unfertilized plots compared to fertilized plots.

Moist soil conditions in the spring of 2003 allowed more than 70 and 80 percent of the target stands to be achieved in spring wheat and spring barley, respectively (Table 11). More plants germinated in fertilized plots than in unfertilized plots of both spring wheat and barley. Plant stand was more than the target stand in no-till spring wheat and barley plots.

Grain yield and yield components

The continuous cereal cropping systems plots are not replicated and therefore combine yield cannot be statistically compared. However, it is statistically acceptable to compare the systems through t-tests conducted on four bundle samples obtained from each plot. Each bundle consisted of four drill rows, 1 m long, which were hand cut and threshed, then analyzed for straw and grain content. The bundle yields were highly correlated to combine yields ($r = 0.94$) and therefore inferences on bundle yields could be applied to combine yield with confidence except in a few cases. In 2002, all fertilized plots produced significantly higher bundle yields than unfertilized plots (Tables 9, 10). Combine data show that the unfertilized plots yielded 54 percent of fertilized plots. In 2003, the yield of fertilized conventional winter wheat, spring wheat, and spring barley was not significantly different from the unfertilized plots (Tables 11, 12). Under the no-till system, yields of fertilized continuous winter wheat and spring barley were significantly higher than the unfertilized plots. The yield of fertilized no-till spring wheat plots was not significantly different from the unfertilized plot.

Conventional tillage

In 2002, among the fertilized conventional tillage plots, spring barley produced significantly higher yields than winter and spring wheat (Tables 9, 10). Winter wheat produced higher yield than spring wheat although the difference was not significant. The results were similar for unfertilized plots. In 2003, results similar to 2002 were obtained when comparing fertilized plots. However, no significant differences were observed among the unfertilized winter wheat, spring wheat, and spring barley.

No-till
In 2002, the CP and the JD 1560 were both used to seed winter wheat and spring barley. In fertilized plots seeded by JD, spring barley produced higher yields than winter and spring wheat (Table 9, 10). Winter and spring wheat bundle yields were not significantly different although spring combine yields were 75 percent of winter wheat combine yields. In fertilized plots seeded by CP, spring barley produced higher yield than winter wheat. In unfertilized plots seeded with JD, the yield of spring barley was significantly higher than that of winter wheat and spring wheat. Spring wheat yield was higher than winter wheat yield. Combine yields followed the same trend (Table 9). The yield of unfertilized plots of winter wheat and spring barley seeded by CP were not significantly different. In general, there were no significant differences in bundle yields of either winter wheat or spring barley planted by either drill. In 2003 only the CP was used. Yields were significantly different between the fertilized plots of winter wheat, spring barley and spring wheat (Tables 11, 12). Spring barley produced the highest yields followed by winter wheat and spring wheat. The high yield in barley was probably attributed to a high number of heads/ft^2 (Table 11).

Conventional tillage vs. no-till
For both 2002 and 2003, the yield of the fertilized conventional and no-till winter wheat was not significantly different. For the unfertilized plots, the yield of no-till winter wheat was significantly lower than that of conventional winter wheat in both years (Tables 9-12). In fertilized plots for both years, conventional spring wheat yields were significantly higher than yields of no-till spring wheat yields. The results were similar for unfertilized plots. In fertilized spring barley, conventional plots produced significantly higher yields than no-till plots in 2002 but the differences were not significant in 2003 (Tables 9-12). In unfertilized plots, conventional spring barley plots produced significantly higher yields than no-till spring barley plots seeded by CP in 2002. No significant differences were observed in JD seeded plots. In 2003, for unfertilized plots, conventional spring barley produced significantly higher yield than no-till spring barley plots (Tables 9-12).

Summary
In both conventional and no-till cropping systems, spring barley produced the highest yield followed by winter wheat and then spring wheat. In winter wheat cropping systems, there was no difference in yield between conventional and no-till systems. Spring wheat and spring barley produced higher yields under conventional tillage than under no-till cropping system.

Crop residue management
No plant counts were done in this experiment in 2002. In 2003 plant stand ranged from 73 to 99percent of target stand (Table 11). The lowest stands were observed in check plots (no N) and the highest stands were observed in manure- and N-applied plots. Grain yields were generally higher in 2003 than in 2002, probably due to more precipitation received in 2003. In 2002, grain yield from the manure treatment was significantly higher than other treatments except the pea vine treatment (Table 9). Grain yields of all the N-fertilized treatments, with or without spring burning, were not significantly different. Grain yields of all the unfertilized plots, with spring or fall burn, were not significantly different and were the lowest yields. Grain yield was highly correlated with heads/ft^2 ($r = 0.71$, $P < 0.0001$) and the manure treatment had

significantly higher heads/ft^2 than other treatments (Table 9). The heads/ft^2 of the pea vine treatment ranked second. In 2003, the manure treatment produced the highest grain yield although this yield was not significantly different from the 40-N and 80-N treatments (Table 11). The lowest yields were obtained on the unfertilized spring and fall burn treatments. Grain yield was highly correlated with heads/ft^2 ($r = 0.62$, $P < 0.0001$) and test weight ($r = 0.86$, $P < 0.0001$). These components were high in the manure and N treatments (Table 10). Data on how much N was added by manure and pea vine are not yet available.

Summary
High yields were obtained when manure or N was applied. Field burning without N application resulted in the lowest yields.

Wheat/pea
In 2002 the pea plant stand was >80 percent of the target stand (Table 9). In 2003, the plant stand was >80 percent except for the no-till pea plots where only 66 percent of the target stand was observed (Tables 9, 11). No wheat stands were determined in 2002. In 2003, wheat stands were >80 percent of target stand except for the no-till plots where the stand was 75 percent of the target stand (Table 11).

Under the wheat system, tillage treatments influenced grain yield in both 2002 and 2003 (Tables 9, 11). In 2002, highest grain yields were produced when plots were plowed in the fall or spring. Grain yield was correlated with bundle yield ($r = 0.81$, $P < 0.0001$) and therefore yield components obtained from bundle samples can be used to explain yield variations in combine data. Grain yield was correlated to heads/ft^2 ($r = 0.66$) and plots plowed in the fall and spring had high numbers of heads/ft^2. Data on weed infestation were not collected in 2002. In 2003, the highest yield was obtained from plots plowed in the spring and fall (Table 11). The lowest yield was produced under no-till where downy brome infestation was significantly higher compared to other treatments. No significant differences were observed among treatments on heads/ft^2 and kernel weight (Table 11).

In 2002, tillage treatments under the pea system significantly influenced grain yield. The no-till system produced the highest pea yields and plowing in the fall resulted in the lowest pea yield (Table 9). In 2003, there were no significant differences in grain yield among all the tillage treatments. However, the lowest yield was produced when plots were plowed in the fall (Table 11). Plant stand did not influence yield (Tables 9, 11).

Summary
For wheat, highest yields were produced when plots were plowed in the fall or spring. The lowest yield was produced in the no-till system where downy brome infestation was significantly high. For peas, the highest yield was produced under the no-till system and the lowest yield was produced when plots were plowed in the fall.

Tillage fertility
Data from the tillage fertility experiment are obtained in alternate years. No data were available in 2002 and data reported below are from 2003. Plant stands in the tillage-fertility plots were not significantly different from each other and ranged from 81 to 84 percent of the target stand (Table 11).

There was no significant interaction between tillage and fertility treatments. Increasing fertilizer rates from 0 to 120 lb N/acre significantly increased grain yield of wheat from 40 to 62 bu/acre (Table 11). Increasing the rate to 160 lb N/acre significantly depressed yields to 59 bu/acre. Grain yield was correlated to heads/ft^2 ($r = 0.56$, $P < 0.0001$). Head counts increased with increasing N rates. Plant stand was not significantly different among the treatments (Table 12) indicating that increased N rates increased tillering. Grain yield at the highest N rate was reduced, probably because soil moisture was depleted before maturity due to increased water demand imposed by increased tillering. The low test weight at the highest N rate is indicative of drought stress (Table 10). The 2003 spring was drier and warmer than normal (Table 8). Downy brome counts were not significantly different among the N treatments (Table 11). Tillage treatments influenced grain yield. The grain yield of the plowed plots was significantly higher than the yield of disk and sweep tillage plots (Table 11). The plow treatment had the highest heads/ft^2 and almost no downy brome infestation compared to the other treatments (Table 11). The sweep treatment, which produced the lowest yield, had the highest downy brome infestation (Table 11).

Summary

Increasing N rates up to 120 lbs/acre increased yield through high numbers of heads/ft^2. The highest yield was produced under the plowed plots, which had a higher numbers of heads/ft^2 than the disked and swept plots. The sweep treatment produced the lowest yield, probably because of a high downy brome infestation.

No-till wheat (summer fallow)

In both no-till treatments, in 2002 and 2003, grain yields generally increased with increasing N fertilization up to 80 lbs/acre, then slightly declined (Table 13). There was little difference between the older set of plots (A) and the newer set of plots (B). Grain yields in the conventional tillage plots, with the same N fertilization rates, were consistently greater. Residue yields showed similar trends as the grain yields (Table 13). Test weights were similar among treatments; however they were generally greater in 2003 than 2002 (Table 13). The 1,000-kernel weights decreased with increasing N fertilization, but were similar between N treatments for both years regardless of the age of the treatments (Table 13).

Table 9. Yield and yield components of crops grown in the CBARC-OSU long-term experiments in the 2002 crop year.

Experiment[1]	Target stand (seeds/ft^2)	Stand (plants/ft^2)	Test wt (lb/bu)	Yield (bu/acre)	1,000-kernel wt combine (oz)	1,000-kernel wt bundle (oz)	Heads/ft^2	Bundle size (ft^2)	HI	Bundle yield (bu/acre)
CWW-CT fertilized	22		60.3	42.1	1.31	1.29	33.5	7.437	0.40	37.6
CWW-CT unfertilized	22		60.3	23.0	1.56	1.29	23.2	7.437	0.44	24.2
NTCWW-Conservapak with N	25		53.9	36.7	0.96	0.98	31.8	13.120	0.32	35.2
NTCWW-JD1560 with N	25		56.7	36.5	1.12	1.00	26.9	8.200	0.32	31.3
NTCWW-Conservapak without N	25		57.8	16.1	1.13	1.01	16.7	13.120	0.33	15.8
NTCWW-1560 without N	25		57.8	12.9	1.14	1.10	16.2	8.200	0.32	11.1
CSB-CT fertilized	23	17.9	48.5	63.4	1.05	1.17	64.6	7.437	0.42	62.9
CSB-CT unfertilized	23	19.4	51.6	42.0	1.24	1.47	45.3	7.437	0.50	51.6
NTCSB-Conservapak with N	26	21	46.7	50.4	1.10	1.13	42.8	13.120	0.42	47.3
NTCSB-JD1560 with N	26	14.1	44.8	43.1	1.10	1.06	42.6	8.200	0.37	39.2
NTCSB-Conservapak without N	26	19.6	46.0	20.4	1.16	1.17	26.4	13.120	0.42	27.0
NTCSB-1560 without N	26	21.1	44.5	23.1	1.12	1.07	44.6	8.200	0.37	45.8
CSW-CT fertilized	26	20	56.3	34.2	0.92	0.73	35.3	7.437	0.41	33.1
CSW-CT unfertilized	26	19.2	58.9	21.8	1.17	0.90	19.9	7.437	0.48	19.6
NTCSW-Conservapak with N	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
NTCSW-JD1560 with N	29	20.5	55.8	27.2	0.91	0.85	25.9	8.200	0.43	26.5
NTCSW-Conservapak without N	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
NTCSW-1560 without N	29	18.9	59.3	15.8	0.94	0.88	23.1	8.200	0.46	16.8
CR-check 1	22		58.4bcd	33.8cd	1.56a		25.0cde	7.437	0.38c	33.0c
CR check 10	22		58.6bcd	35.6cd	1.57a		24.6e	7.437	0.4bc	29.7c
CR 2-spring burn 40#N/A	22		59.6b	49.5b	1.59a		29.8bcd	7.437	0.41abc	47.4b
CR 3-spring burn 80#N/A	22		61a	49.7b	1.60a		29.6bcd	7.437	0.43ab	48.2b
CR 4-40#N/A	22		59.6bc	50.6b	1.54a		29.6bcd	7.437	0.42abc	47.7b
CR 5-80#N/A	22		60.9a	50b	1.60a		31.1bc	7.437	0.45a	51.5b
CR 6-Fall burn	22		58.1d	28.8d	1.58a		23.3e	7.437	0.4bc	28.9c
CR 7-Spring burn	22		58.3cd	32.6cd	1.60a		24.9de	7.437	0.39c	31.6c
CR 8-Manure	22		58.1d	60.5a	1.40b		46.5a	7.437	0.43ab	73.9a
CR 9-Pea vine	22		59.6b	55.3ab	1.65a		34.6b	7.437	0.39c	54.3b
P-2 wheat-fall plow	22		55.8ab	46a	1.08a		37.2a	7.437	0.41a	41.4b
P-2 wheat-spring plow	22		56.3a	47.8a	1.08a		39.1a	7.437	0.41a	46.9a
P-2 wheat-maxi till (chisel)	22		55.6b	40.9b	1.09a		38.1a	7.437	0.41ab	41.2b
P-2 wheat-no-till	25		55.6b	33.4c	1.07a		23.7a	8.202	0.38b	27.1c
P-2 pea-F plow	8	6.6ab	62.3a	451.7d	6.38b			7.437	0.21a	653.1b
P-2 pea-S plow	8	7.4a	61.3b	753.8b	7.11a			7.437	0.26a	984.2a
P-2 pea-maxi till (disk)	8	6.4b	62a	688.1c	7.10a			7.437	0.24a	837.7ab
P-2 pea-no-till	8	6.7ab	62.1a	1091.7a	7.22a			8.202	0.26a	1064.6a

[1]CWW-continuous winter wheat; CSW-continuous spring wheat; CSB-continuous spring barley; CT-conventional tillage; NT-no-till; CR-crop residue; P-2-wheat/pea; TF-tillage, fertility; N-nitrogen; HI-harvest index; ct-count; bu-bush

Table 10. T-test comparisons of mean bundle yield under different continuous cereal cropping systems in 2002 (Pr > t).

	ctcwwf[1]	ntcwwfcon	ntcwwfjd	ctcswf	ntcswfjd	ctcsbf	ntcsbfcon	ntcsbfjd	ctcwwnf	ntcwwnfcon	ntcwwnfjd	ctcswnf	ntcswnfjd	ctcsbnf	ntcsbnfcon
ctcwwf	-														
ntcwwfcon	ns[2]	-													
ntcwwfjd	ns	ns	-												
ctcswf	ns	ns	ns	-											
ntcswfjd	*	ns	ns	*	-										
ctcsbf	**	**	****	****	****	-									
ntcsbfcon	ns	*	*	*	**	*	-								
ntcsbfjd	ns	ns	***	**	**	****	ns	-							
ctcwwnf	*	ns	ns	*	ns	***	**	**	-						
ntcwwnfcon	**	**	***	****	**	****	***	****	*	-					
ntcwwnfjd	**	**	**	****	**	****	**	***	*	ns	-				
ctcswnf	**	55	**	***	*	****	**	***	ns	*	**	-			
ntcswnfjd	**	**	**	****	**	****	**	***	*	ns	*	*	-		
ctcsbnf	ns	*	**	*	**	*	ns	*	**	**	***	**	**	-	
ntcsbnfcon	ns	ns	ns	ns	ns	**	*	*	ns	ns	**	ns	*	****	-
ntcsbnfjd	ns	*	*	*	*	*	ns	ns	*	**	**	**	**	ns	*

[1]ctcwwf – conventional tillage, continuous winter wheat, fertilized
ctcswf– conventional tillage, continuous spring wheat, fertilized
ctcsbf– conventional tillage, continuous spring barley, fertilized
ctcwwnf – conventional tillage, continuous winter wheat, no fertilizer
ctcswnf– conventional tillage, continuous spring wheat, no fertilizer
ctcsbnf– conventional tillage, continuous spring barley, no fertilizer
ntcwwfcon – no-tillage, continuous winter wheat, fertilized, conservapak drill
ntcwwfjd– no-tillage, continuous winter wheat, fertilized, John Deere drill
ntcswfjd– no-tillage, continuous spring wheat, fertilized, John Deere drill
ntcsbfcon– no-tillage, continuous spring barley, fertilized, conservapak drill
ntcsbfjd– no-tillage, continuous spring barley, fertilized, John Deere drill
ntcwwnfcon – no-tillage, continuous winter wheat, no fertilizer, conservapak drill
ntcwwnfjd– no-tillage, continuous winter wheat, no fertilizer, John Deere drill
ntcswnfjd– no-tillage, continuous spring wheat, no fertilizer, John Deere drill
ntcsbnfcon– no-tillage, continuous spring barley, no fertilizer, conservapak drill
ntcsbnfjd– no-tillage, continuous spring barley, no fertilizer, John Deere drill

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

Table 11. Yield and yield components of crops grown in the CBARC-OSU long-term experiments in the 2003 crop year.

Experiment[1]	Target stand (seeds/sq ft)	Stand (plants/sq ft)	Downy brome ct (1ft^2)	Test wt (lb/bu)	Yield (bu/acre)	1,000-kernel wt combine(oz)	1,000-kernel wt bundle(oz)	Heads/ft^2	Bundle size (ft^2)	HI	Bundle yield (bu/acre)
CWW-CT fertilized	22	10.8	1.2	50.9	35.6	0.93	0.93	25.4	7.437	0.34	37.4
CWW-CT unfertilized	22	12.8	0.1	57.7	28.3	1.50	1.48	17.1	7.437	0.46	32.6
NTCWW-Conservapak with N	25	18.8	clearfield	58.9	40.7	0.95	1.00	34.7	13.120	0.40	40.8
NTCWW-Conservapak without	25	21.4	clearfield	60.5	21.9	1.13	1.11	34.5	8.200	0.42	20.9
CSB-CT fertilized	23	20.6		47.6	61.6	1.07	1.09	54.4	7.440	0.43	58.2
CSB-CT unfertilized	23	18.9		50.7	37.4	1.24	1.31	37.1	7.440	0.52	49.6
NTCSB-Conservapak with N	26	37		47.1	58.3	1.06	1.01	52.5	13.120	0.46	58.7
NTCSB-Conservapak without N	26	21.4		48.5	24.6	1.21	1.21	22.6	13.120	0.61	24.1
CSW-CT fertilized	26	22.6		54.6	29.3	0.78	0.81	41.8	7.440	0.32	34.0
CSW-CT unfertilized	26	20.6		60.8	31.7	1.24	0.94	27.7	7.440	0.39	31.3
NTCSW-Conservapak with N	29	30		55.4	25.0	0.77	0.80	32.0	13.120	0.27	22.9
NTCSW-Conservapak without N	29	22.2		60.3	24.1	1.15	1.15	29.1	13.120	0.42	25.2
CR-check 1	22	16c		57.2d	36.8e	1.498d		26.5bcd	7.437	0.4c	47.2cd
CR-check 10	22	17.6bc		57.0d	39.6e	1.565abc		21.1d	7.437	0.41bc	37.5d
CR 2-Spring burn 40#N/A	22	18.4abc		58.8bc	64.7bcd	1.515cd		28.8abcd	7.437	0.4bc	59b
CR 3-Spring burn 80#N/A	22	21.8abc		59.5a	60.7cd	1.512cd		29.9abc	7.437	0.4bc	55.5bc
CR 4-40#N/A	22	18.6abc		59.4ab	66.6abc	1.544abcd		32.0ab	7.437	0.42ab	65b
CR 5-80#N/A	22	18bc		59.6a	69.1ab	1.544abcd		30.5ab	7.437	0.41bc	61.2b
CR 6-Fall burn	22	19.4abc		56.7d	34.4e	1.533bcd		22.3cd	7.437	0.4c	38.3d
CR 7-Spring burn	22	17.8bc		57.1d	35.8e	1.586ab		24.9bcd	7.437	0.41bc	42.4d
CR 8-Manure	22	19.9abc		59.2ab	73.1a	1.586ab		35.6ab	7.437	0.44a	90.6a
CR 9-Pea vine	22	18.8abc		58.3c	58.2d	1.593a		31.9ab	7.437	0.42bc	61.2b
P-2 wheat-fall plow	22	17.7ab	0.2c	56.6b	47b	0.92a		37.2a	7.437	0.31a	52.5ab
P-2 wheat-spring plow	22	19.5a	0.3c	57.8a	49.7a	0.94a		39.8a	7.437	0.31a	55.0a
P-2 wheat-maxi till (chisel)	22	18.3ab	5.8b	57.0ab	44.6c	0.95a		39.9a	7.437	0.3a	46.0ab
P-2 wheat-no-till	25	18.8b	11.1a	56.9ab	43.4c	0.92a		33.1a	11.200	0.28a	42.2b
P-2 pea-fall plow	7	6.2a		62.9b	777.4a	5.22a			7.440	0.52a	1118a
P-2 pea-spring plow	7	5.9a		62.2c	830.3a	5.32a			7.440	0.54a	1145a
P-2 pea-maxi till (disk)	7	5.6a		63.3a	832.1a	5.18a			7.440	0.51a	1268a
P-2 pea-no-till	7	4.6a		62.9b	830.6a	5.22a			10.940	0.52a	777b
TF 0#N	22	18.5a	11.2a	57.8b	40.8c	1.46a		21.7d	7.437	0.39bc	40.8b
TF 40#N	22	18.1a	22.4a	58.9a	63.9a	1.43ab		30.9c	7.437	0.40a	65.5a
TF 80#N (3)	22	17.9a	21.4a	59.3a	64.5a	1.38bc		31.7bc	7.437	0.40a	66.1a
TF 80#N (4)	22	18.1a	15.9a	59a	62.6a	1.37c		31.1c	7.437	0.40ab?	65.2a
TF 120#N	22	18.4a	19.1a	58b	61.8a	1.27d		33.8b	7.437	0.39c	63.6a
TF 160#N	22	18.1a	12.0a	56.7c	58.5b	1.22e		37.4a	7.437	0.38c	64.3a
TF Plow	22	17.6a	0.1b	57.9b	63.3a	1.33b		33.5a	7.437	0.39a	65.8a
TF Disk	22	18.3a	7.6b	57.9b	59.4b	1.33b		32.0a	7.437	0.39a	62.6a
TF Sweep	22	18.6a	43.3a	59a	53.2c	1.41a		27.7b	7.437	0.40a	54.3b

[1]CWW-continuous winter wheat; CSW-continuous spring wheat; CSB-continuous spring barley; CT-conventional tillage; NT-no-till; CR-crop residue; P-2-wheat/pea; TF-tillage, fertility; N-nitrogen; HI-harvest index; ct-count; bu-bushel.

Table 12. T-test comparisons of mean bundle yield under different continuous cereal cropping systems in 2003 (Pr > t).

	ctcwwf[1]	ntcwwf	ctcswf	ntcswf	ctcsbf	ntscbf	ctcwwnf	ntcwwnf	ctcswnf	ntcswnf	ctcsbnf
ctcwwf	-										
ntcwwf	ns[2]	-									
ctcswf	ns	**	-								
ntcswf	**	**	**	-							
ctcsbf	**	*	**	**	-						
ntscbf	***	**	***	***	ns	-					
ctcwwnf	ns	ns	ns	*	**	**	-				
ntcwwnf	**	**	**	ns	**	***	*	-			
ctcswnf	ns	*	ns	*	**	**	ns	**	-		
ntcswnf	**	**	**	ns	**	****	ns	ns	ns	-	
ctcsbnf	ns	ns	*	*	ns	ns	ns	**	*	*	-
ntscbnf	*	**	**	ns	**	****	ns	ns	ns	ns	*

[1] ctcwwf – conventional tillage, continuous winter wheat, fertilized
ctcswf– conventional tillage, continuous spring wheat, fertilized
ctcsbf– conventional tillage, continuous spring barley, fertilized
ctcwwnf – conventional tillage, continuous winter wheat, no fertilizer
ctcswnf– conventional tillage, continuous spring wheat, no fertilizer
ctcsbnf– conventional tillage, continuous spring barley, no fertilizer
ntcwwf – conventional tillage, continuous winter wheat, fertilized, conservapak drill
ntcswf– conventional tillage, continuous spring wheat, fertilized, conservapak drill
ntcsbf– conventional tillage, continuous spring barley, fertilized, conservapak drill
ntcwwnf – conventional tillage, continuous winter wheat, no fertilizer, conservapak drill
ntcswnf– conventional tillage, continuous spring wheat, no fertilizer, conservapak drill
ntcsbnf– conventional tillage, continuous spring barley, no fertilizer, conservapak drill

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

Table 13. Effect of nitrogen fertilization on grain yield, test weight, straw yield, and 1,000-kernel weight of no-till winter wheat grown at the Columbia Plateau Conservation Research Center-ARS at Pendleton, Oregon, 2001-2002 and 2002-2003.

2001-2002 N	Yield A	Yield B	Yield C	Test wt A	Test wt B	Test wt C	Straw yield A	Straw yield B	Straw yield C	1000-kernel wt A	1000-kernel wt B	1000-kernel wt C
lbs/acre		bu/acre			lbs/bu			---t/acre---			---oz---	
0	38.2	44.7	60.8	58.1	58.3	58.7	2.03	2.25	3.16	1.57	1.60	1.75
40	58.1	61.0	--	58.9	59.1	--	3.26	3.09	--	1.54	1.51	--
80	71.5	72.6	--	59.0	59.8	--	3.85	4.26	--	1.38	1.40	--
120	61.9	67.3	73.0	56.6	57.7	55.4	3.81	4.08	4.20	1.23	1.31	1.12
160	56.2	58.9	--	54.1	56.2	--	4.28	4.32	--	1.20	1.25	--

2002-2003 N	Yield A	Yield B	Yield C	Test wt A	Test wt B	Test wt C	Straw yield A	Straw yield B	Straw yield C	1000-kernel wt A	1000-kernel wt B	1000-kernel wt C
lbs/acre		bu/acre			lbs/bu			---t/acre---			---oz---	
0	37.7	42.1		58.5	58.9	59.2	2.11	1.80	2.43	1.51	1.54	1.37
40	62.4	64.6	--	58.9	59.3	--	3.41	2.66	--	1.50	1.52	--
80	81.8	72.9	--	59.2	59.7	--	4.35	3.14	--	1.36	1.46	--
120	74.5	81.7		57.0	58.5	58.9	5.06	5.09	5.65	1.23	1.23	1.48
160	82.1	86.2	--	55.4	57.8	--	6.13	4.34	--	1.02	1.18	--

Means of four replications

POST-HARVEST TILLAGE IS INCONSISTENT FOR MANAGING JOINTED GOATGRASS IN WINTER WHEAT

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Abstract

We conducted this study to evaluate the effects of post-harvest tillage on jointed goatgrass (JGG) emergence and interference in winter wheat over a 5-year period in a conventional dryland wheat-fallow crop rotation. The study consisted of two trials located at the Columbia Basin Agricultural Research Center in Moro, Oregon. The first trial was established in September of 1998 and the second in September of 1999. Both trials were established on winter cereal stubble on adjacent sites with no previous history of JGG infestation. Main plots consisted of six different post-harvest tillage timings on wheat stubble. Treatments consisted of 1) early post-harvest disking, 2) disking in late fall, 3) disking in early spring, 4) disking in late spring, 5) disking at all tillage timings, or 6) no tillage. Main plots were split into two sub-plots consisting of a low or high JGG density achieved by seeding JGG spikelets into standing cereal stubble at the start of each trial. Post-harvest disking had little effect on percent crop residue cover. As expected, the high JGG density sub-treatments had greater JGG densities, spike counts, and biomass each year than did the low JGG density sub-treatments in both trials. The high JGG density sub-treatment reduced wheat yield and JGG dockage in all years of both trials. Post-harvest tillage had little effect on JGG on the first trial site, but in the second trial site in the presence of high JGG populations, there was a significant reduction in JGG density, spike counts, and biomass in wheat when post-harvest tillage was done after wheat harvest in the fall. Post-harvest tillage did not influence wheat yield in either trial, but JGG dockage was reduced by tillage soon after wheat harvest, or later in the fall. Since reductions in JGG from fall disking were not observed in both trials, this leads to a general conclusion that post-harvest tillage effects on JGG populations can be beneficial but inconsistent between years. The yearly variation in environmental factors, especially growing season precipitation, had a more significant influence on JGG populations than did post-harvest tillage in these studies.

Key words: Jointed goatgrass, residue management, tillage, winter wheat, yield.

Introduction

Jointed goatgrass (JGG) continues to be a serious weed problem in winter wheat in the western United States. It does not only cause yield losses by competing with the crop for soil moisture, but JGG spikelets can contaminate the harvested grain, causing dockage losses at the grain elevator and further financial losses to the grower. Due to the genetic similarity between JGG and wheat, selective chemical control is difficult to acheive in the growing wheat crop. Rotation of winter wheat with broadleaf crops can facilitate long-term JGG control because selective grass herbicides can be utilized. However, relying on chemical control alone is not a good long-term solution because weed resistance to herbicides can become a problem. Another JGG management approach is to grow spring seeded crops in rotations with winter wheat. Spring seeded broadleaf or cereal crops can help reduce JGG problems because JGG typically germinates in the fall and can be controlled prior to planting spring seeded crops. However, in areas with limited rainfall, annual or spring cropping is often not considered to be a profitable alternative. In addition, recent research has shown that JGG can complete its life cycle and produce seed in spring cereal crops. In a winter wheat-fallow rotation, control of JGG during the fallow period is essential to help minimize increases in JGG infestations. The study described in this report was designed to determine if a shallow tillage after wheat harvest would result in reductions of JGG during the following wheat crop.

Methods

A study was conducted in dryland wheat at the Columbia Basin Agricultural Research Center, near Moro, Oregon. The study consisted of two trials; the first was established in September 1998, and the second in September 1999 in close proximity to the first trial. Both trials were arranged in a randomized complete block, split-plot design with five replications. Main treatments consisted of six post-harvest stubble tillage timings that included: 1) post-harvest disking soon after wheat harvest, 2) disking of wheat stubble in late fall, 3) disking in early spring, 4) disking in late spring, 5) disking at all tillage timings, and 6) no tillage. Tillage operations consisted of disking standing grain stubble twice with a John Deere 620 tandem disk with 20-inch discs at 7.5-inch spacing. Main plots were 40 by 50 ft in size. Sub-plots consisted of a target JGG density of 5 (low density) or 75 (high density) JGG joints per m^2 seeded into standing cereal stubble using a drop-type seed spreader on September 4, 1998 in the first trial and on September 13, 1999 in the second trial. Sub-plots were 20 by 50 ft in size.

After the last post-harvest stubble disking treatments were performed in the spring, operations to establish conventional summer fallow consisted of a glyphosate application to all treatments, chisel plowing, cultivation, and rodweeding. No glyphosate application was needed on wheat stubble in the fall on any treatment, in any year, due to dry autumn conditions that prevailed at the study sites. Percent residue cover on the first study was estimated on December 9, 1999. Percent residue cover was not estimated further in either study. Jointed goatgrass plant counts were taken in wheat stubble each spring before final fallow tillage operations were performed by counting JGG plants per m^2 in three locations along a diagonal transect in each plot. Wheat and JGG plant counts, spike counts and biomass per m^2 estimates were obtained prior to harvest during each year that plots were planted to winter wheat. Winter wheat was harvested each crop year using a small plot combine. Jointed goatgrass dockages were estimated by taking a 750-ml sample of harvested grain from each plot, weighing the sample, separating goatgrass spikelets from the wheat, and weighing them. Percent dockage was estimated using the following formula: (weight of JGG spikelets ÷ weight of wheat) x 100 = percent dockage.

Results and Discussion

Post-harvest tillage (light disking of wheat stubble) had a relatively minor effect on percent crop residue cover (data not shown). As expected, the high JGG density sub-treatments had greater JGG densities, spike counts, and biomass each year than did the low JGG density sub-treatments in both trial sites (Tables 1- 3). The high JGG density also had reduced wheat yield and increased JGG dockage in both trial sites (Table 4).

Table 1. Influence of post-harvest tillage timing on jointed goatgrass plant densities in subsequent wheat crops, near Moro, Oregon.

Tillage timing[1]	First trial (est. 1998)[2] 3-27-00	First trial (est. 1998)[2] 3-26-02	Second trial (est. 1999) 4-18-01	Second trial (est. 1999) 3-27-03
	plants/m²			
Low JGG				
Early post-harvest	0	2	0	0
Fall	0	3	0	1
Early spring	1	5	0	1
Late spring	1	3	0	1
All times	0	3	0	1
No tillage	0	2	0	2
High JGG				
Early post-harvest	3	8	0	3
Fall	4	10	0	3
Early spring	4	11	1	9
Late spring	4	10	1	7
All times	4	9	1	2
No tillage	3	9	1	9
LSD (0.05) tillage (A)	ns	ns	0.3	2.6
JGG population (B)	0.5	1.0	0.2	1.2
(A) x (B)	ns	ns	0.5	2.8

[1] Low JGG and high JGG seeded with 5 or 75 JGG spikelets/m² on first and second trials in September 1998 and September 1999, respectively.

[2]First trial site was in crop in 2000 and 2002. Second trial site was in crop 2001 and 2003.

Table 2. Influence of post-harvest tillage timing on jointed goatgrass spike counts in subsequent wheat crops, near Moro, Oregon.

	First trial (est. 1998)[2]		Second trial (est. 1999)	
Tillage timing[1]	JGG 6-02-00	JGG 7-18-02	JGG 6-14-01	JGG 7-2-03
	---------- plants/m^2 ----------			
Low JGG				
Early post-harvest	1	8	0	0
Fall	2	6	0	9
Early spring	3	11	3	4
Late spring	3	4	1	8
All times	4	9	0	1
No tillage	2	2	1	10
High JGG				
Early post-harvest	25	67	2	16
Fall	33	56	4	8
Early spring	31	60	14	56
Late spring	31	62	9	43
All times	22	59	9	25
No tillage	29	45	18	46
LSD (0.05) tillage (A)	ns	ns	5.6	17.4
JGG population (B)	3.5	11.1	2.5	11.4
(A) x (B)	ns	ns	6.2	ns

[1]Low JGG and high JGG seeded with 5 or 75 JGG spikelets/m^2 on first and second trials in September 1998 and September 1999, respectively.
[2]First trial site was in crop in 2000 and 2002. Second trial site was in crop 2001 and 2003.

Table 3. Influence of post-harvest tillage timing on wheat and jointed goatgrass plant biomass in subsequent wheat crops, near Moro, Oregon.

Tillage timing[1]	First trial (est. 1998)[2]				Second trial (est. 1999)	
	Wheat 6-29-00	JGG 6-29-00	Wheat 7-18-02	JGG 7-18-02	Wheat Jul-2-03	JGG Jul-2-03
	g/m²					
Low JGG						
Early post-harvest	530	1	592	2	652	0
Fall	519	0	596	1	665	0
Early spring	518	0	614	2	933	4
Late spring	523	1	551	4	706	4
All times	500	0	638	3	977	0
No tillage	497	0	625	3	664	5
High JGG						
Early post-harvest	528	5	561	12	638	8
Fall	450	9	609	10	678	0
Early spring	503	11	639	11	795	16
Late spring	518	9	498	10	717	29
All times	526	10	585	8	826	4
No tillage	482	8	564	9	643	23
LSD (0.05) tillage (A)	ns	ns	52.7	ns	92.9	10.1
JGG population (B)	ns	1.4	25.4	2.1	42.8	3.4
(A) x (B)	ns	ns	ns	ns	ns	8.4

[1]Low JGG and high JGG seeded with 5 or 75 JGG spikelets/m² on first and second trials in September 1998 and September 1999, respectively.
[2]First trial site was in crop in 2000 and 2002. Second trial site was in crop 2001 and 2003.

Table 4. Influence of post-harvest tillage timing on wheat yield and dockage in subsequent wheat crops, near Moro, Oregon.

Tillage timing[1]	First trial (est. 1998)[2]				Second trial (est. 1999)			
	Yield 7-25-00	Dockage 7-25-00	Yield 7-18-02	Dockage 7-18-02	Yield 8-01-01	Dockage 8-01-01	Yield 7-28-03	Dockage 7-28-03
	bu/acre	%	bu/acre	%	bu/acre	%	bu/acre	%
Low JGG								
Early post-harvest	64	.02	35	0.11	43	0.01	39	0.05
Fall	62	.01	39	0.11	38	0	40	0.10
Early spring	65	.01	38	0.15	42	0.01	45	0.05
Late spring	66	.02	32	0.06	41	0.03	46	0.02
All times	63	.02	37	0.11	41	0	42	0.02
No tillage	63	.03	36	0.10	41	0.03	45	0.11
High JGG								
Early post-harvest	58	.17	33	0.90	41	0.09	39	0.30
Fall	58	.17	36	0.78	37	0.03	37	0.10
Early spring	61	.18	35	0.97	41	0.27	41	0.29
Late spring	60	.17	35	0.80	40	0.21	45	0.59
All times	61	.18	36	0.82	37	0.04	37	0.07
No tillage	58	.19	33	0.52	38	0.24	39	0.33
LSD (0.05) tillage (A)	ns	ns	ns	ns	ns	ns	ns	0.15
JGG population (B)	1.6	0.02	1.7	0.20	1.1	0.05	2.8	0.07
(A) x (B)	ns	ns	ns	ns	ns	0.12	ns	0.18

[1]Low JGG and high JGG seeded with 5 or 75 JGG spikelets/m^2 on first and second trials in September 1998 and September 1999, respectively.
[2]First trial site was in crop in 2000 and 2002. Second trial site was in crop 2001 and 2003

.Post-harvest tillage treatments had no significant influence on JGG at the first trial site. However, in the second study site, JGG plant density, spike counts, and biomass were significantly reduced in both years of wheat crop when post-harvest tillage was performed after wheat harvest in August or in October (Tables 1-3). No differences in crop yield were observed from the fall tillage treatments. However, in the second trial site, at the high JGG density, JGG dockage was reduced when post-harvest tillage was performed after wheat harvest in August or in October (Table 4).

Since the fall tillage effects on JGG populations were not consistently observed in both trials, it leads to a general conclusion that effects of post-harvest tillage on JGG populations and subsequent wheat yield and dockage can be generally beneficial but not consistently so. The yearly variation in environmental factors, especially growing season precipitation, had a more significant influence on JGG populations than did post-harvest tillage in these studies. In addition, since post-harvest tillage did not have a negative impact on the JGG problem in these trials, it may have value as a residue management tool in certain production systems.

POTENTIAL ALTERNATIVE CROPS FOR EASTERN OREGON

Stephen Machado

Abstract

The winter wheat/summer fallow rota-tion is the most common cropping system in eastern Oregon. It is used to store winter precipitation and control weeds. This cropping system, however, destroys soil organic carbon, reduces water infiltration and thus leads to soil erosion, and is not sustainable. Conservation tillage, annual cropping, and the introduction of alternative crops are ways to improve sustainability of cropping systems in eastern Oregon. The following review briefly discusses the uses, climatic requirements, and yield potential of potential alternative crops for eastern Oregon. These crops include legumes, cereals, and crops with industrial and pharmaceutical uses. Based on this review, research should focus on evaluating potential alternative crops for suitability to eastern Oregon conditions and provide growers with information they need to integrate these crops into existing cropping systems.

Introduction

The Pacific Northwest (PNW) Columbia Plateau is semi-arid with rainfall ranging from 12 to 18 inches. About 70 percent of annual precipitation occurs from November to April during winter and water available to plants during spring and summer depends on how much water is stored in the soil. Because of steep slopes prevalent in the PNW, soil erosion is a major problem in fields that do not have sufficient residue cover. Cropping systems that improve water infiltration and storage, reduce evapo-ration, and increase water use efficiency of crops on a sustainable basis should be developed.

Wheat/fallow rotation is the traditional crop production system in the PNW Columbia Plateau. The winter wheat / summer fallow rotation is used on 4.5 million acres in the drier portion of the region, where rainfall is considered inadequate to produce a crop every year. This cropping system is most eco-nomical where rainfall is less than 13 inches. Summer fallowing is used to store winter precipitation and control weeds. This cropping system, however, depletes soil organic carbon and reduces water infiltration, leading to soil erosion (Rasmussen and Parton 1994). In the long-run, soil productivity decreases. Research should focus on developing biologically and economically sustain-able farming systems. Conservation tillage, annual cropping, and the introduction of alternative crops are ways to improve sustainability of cropping systems in the PNW.

No-till (direct-seeding) systems increase infiltration, reduce runoff, and reduce tillage costs but adoption has been slow. This is primarily because of cultural inertia, cost of equipment, and uncertain crop yields due to weed and disease build up (Williams and Wuest 2001).

Annual cropping is limited by low rainfall and soil moisture. Planting every year, however, has the potential to reduce soil erosion when compared to summer fallow. When annual cropping includes alternative crops and spring plantings, weeds and diseases can be controlled (Williams and Wuest 2001).

Cropping systems that include alter-native crops should improve soil fertility and structure and reduce weed and disease incidences. Alternative crops, however, suffer from lack of markets and stable prices and their yields have been inconsistent primarily because they are not well adapted to the environmental conditions of the PNW. Furthermore, research on their agronomy is lagging. More work should be done to evaluate the sustainability of cropping systems that include alternative crops. Below is a brief description of alternative crops that have production potential in the PNW and their uses.

Alternative Crops and their Uses

Soil productivity can be sustained by inclusion of alternative crops in rotation with wheat. Different alternative crops improve soil productivity in different ways. Alternative crops, when carefully chosen, can be used to improve soil water storage, fertility, and structure, and reduce disease incidence. Agronomic and economic assessments of alternative crops in cereal-based rotations should be conducted. Potential alternative crops for the PNW include legumes, oilseeds, and other cereals besides common wheat.

Legumes

Legumes (pulse crops) can improve the production potential of subsequent cereal crops. Legumes fix nitrogen (N) and reduce N applications for the following cereal crop. In addition legumes reduce disease incidences of other crops in rotation. However, soil erosion can be a serious problem in crop rotations with grain legumes followed by winter wheat. Legumes produce relatively little crop residue, and it is fragile and decomposes rapidly under most conditions. This problem can, however, be overcome by reduced tillage where the legume is planted in the stubble of the previous spring or winter cereal.

Legumes can be classified as cool- and warm-season crops. They are low in fat, rich in fiber and complex carbohydrates, and are good sources of vitamins. Consumption of these healthy foods has been increasing. Some pulses, most notably soybean and peas, are important livestock feed. Other legumes have pharmaceutical and industrial uses.

Cool Season Food Legumes

Cool-season legumes are long day plants, i.e., they grow vegetatively during the cool season and flower and produce seeds when daylengths are progressively longer. Examples of cool season food legumes include chickpea, faba bean, field pea, grasspea, lentil, and lupin. These legumes originated in the Near East (Smartt 1990) and spread to the cool-temperate areas of central and northern Europe, from where they found their way into the western hemisphere (Muehlbauer 1991).

Dry pea, lentil, and chickpea are produced in the Palouse region of eastern Washington and northern Idaho, while the coastal region of south-central California is of equal importance for chickpea. There is renewed interest in lupins in eastern Oregon. Lupins were first introduced to the United States in the 1930's but production had almost disappeared by the 1960's. Faba beans have not gained any popularity as food in the United States. They are mostly used for livestock feed either as grain or as green forage and overseas market outlets have not been developed. Scattered areas of faba bean production can be found in western Washington, irrigated areas of Montana and Wyoming, and several northeastern states.

Expanded production of the cool-season food legumes depends on increased domestic usage and the development of overseas markets. Large areas of the arid western states could successfully produce cool-season pulses if uses and outlets were developed. If ranked for their ability to produce under dry conditions, grasspea would come first followed by lentil, chickpea, pea, and finally faba bean (Muehlbauer 1993). Lupin would probably be between lentil and chickpea.

Grasspea

Grasspea (*Lathyrus sativus* L.) or chickling vetch is a creeping vine. It is widely grown in Bangladesh, India, and to a lesser extent in the Middle East, southern Europe, and some parts of South America. Grasspea is usually grown for grain but can be used for fodder. As a pulse, grasspea is very high in protein, but a neurotoxic amino acid that is present in wild and most cultivated forms has prevented it from developing into an important food legume. If the toxin is consumed in sufficient amounts it can cause the irreversible crippling disease known as lathyrism (Smartt 1990). New cultivars contain reduced toxin levels.

Grasspea has great potential in semi-arid areas of eastern Oregon where drought strongly restricts the yield of most current pulse crops. It can be used as a drought-tolerant green manure. This annual legume can provide ground cover as an alternative to summer fallow, helping to prevent wind and water erosion, as well as adding N to the soil (Small 1999). Grasspea could become an important feed grain crop in the semi-arid western states if yields can be improved and low neuro-toxin cultivars can be developed.

Lentil

Lentil *(Lens culinaris* L.*)* is widely grown in semi-arid regions of the Near East, northern Africa, and the Indian subcontinent. Lentil was widely grown in southern and central Europe but was discontinued due to difficulties associ-ated with harvesting. Because of the plant's short stature, mechanical harvesting was impossible and farmers relied on hand pulling of the plants. The International Center for Agricultural Research in the Dry Areas (ICARDA) in Syria is now developing tall upright lentil germplasm adaptable to mechanical harvesting. Of the southern European countries, only Spain remains as a major producer of the crop. Lentil, like chickpea, has no antinutritional factors except for ingredients that cause flatulence (Muehlbauer 1993).

The first commercial domestic production of lentil took place in 1937 near Farmington, Washington. Production expanded until 1981 when nearly 222,390 acres were produced. Since then, production has stabilized at about 111,195 acres annually (Muehlbauer et al. 1985). Fluctuations in production are a response to variable export market demands, as nearly 90 percent of the crop is exported.

Lentil outperforms all other legumes except grasspea when precipitation is below 14 inches, and in the coldest climates, making it suitable for eastern Oregon. Grain yields of 300 to 1,200 lbs/acre have been observed (Rasmussen and Smiley 1994; Machado et al., *unpublished data*)

Lupin

Lupin (*L. albus* L., *L. augustifolius* L., *L. luteus* L., *L. mutabalis* L., *and L. cosentenii* L.) is a cool-season grain legume or forage crop. It is cultivated worldwide, in climates ranging from northern Europe and Russia, to the arid Australian plains and the Andean highlands. Both spring-sown and fall-sown types are grown, but only the spring types are adapted to the northern midwestern United States, northeastern United States, and Canada. Lupin is one of the few grain legumes that compares to soybean in seed protein content (Hymowitz 1990). The large seed and lack of anti-nutritional factors make lupin a potential crop for many animal feed formulations, for direct feeding, and as a human food. Care must be taken, however, to produce alkaloid-free lupins. Lupin grain is high in protein and energy, is low in fat, and has good fiber digestibility. However, because of its historically bitter seed, lupin production represents a small fraction of a percent of the grain legumes grown worldwide (Williams 1986).

Lupin was first introduced into the United States in the 1930's by USDA researchers, primarily as a green manure or cover crop in the southern Cotton Belt. By 1950, the area under lupin production had increased to over one million acres in the "Lupin Belt," the coastal plain stretching across the southeastern United States. Reeves (1991) attributed the disappearance of lupins in the 1960's to increased availability of cheap N fertilizers and lack of government support. Work to improve white lupin lines by Fred Elliott, however, continued and several new cultivars were introduced in Minnesota and Canada in the early 1980's (Putnam et al. 1991). Efforts by plant breeder Gene Aksland (Resource Seeds, Gilroy, CA), and experimental work in the PNW and Canada were important in introducing the crop to those regions in the 1980's.

Lupin has big potential for eastern Oregon. In recent experiments at Pendleton and Moro, narrow-leaf lupin varieties yielded more than 1,120 lbs/acre (Chen et al. 2001). Lupin yields in northern Idaho averaged less than 1,000 lbs/acre. Lupins can fix 168 to 224 lbs N/acre (Reeves et al. 1990). Although lupins possess an upright growth habit attractive for direct harvesting, their large seed size necessitates high seeding rates and make proper establishment with commercial small-grain drills difficult (Muehlbauer 1993). Higher seeding costs limit lupin production for green manure or forage purposes. Like soybean, lupin does not flower in northern Idaho until the moisture and temperature stress periods of July and August. No flowering problems have been shown in the narrow leaf lupins that were evaluated in eastern Oregon (Chen et al. 2001). No serious insect problems have been observed, but powdery mildew and bacterial pod blight have been observed on lupin crops grown in northern Idaho.

Chickpea

Chickpea *(Cicer arietinum* L.*)* is an annual plant that generally requires a cool season. India is the major producer of chickpea with nearly 17.5 million acres under production (Smithson et al. 1985). Chickpeas are classified as either *desi* (small seeded) or *kabuli* or garbanzo (large seeded) types. The *desi* types predominate in the Indian subcontinent while the *kabuli* types predominate elsewhere. About 15,000 acres of chickpea are produced annually in California and the Palouse region of eastern Washington and northern Idaho, although there is scattered production in several other western states (Muehlbauer 1993). *Kabuli* types dominate American production because of their high value for use as an ingredient in salad bars; however, there is a small but steadily increasing production of *desi* types. The small amount of *desi* chickpeas produced is currently marketed to ethnic communities in large cities, but there are prospects of increasing production for export (Muehlbauer 1993).

Kabuli chickpeas offer higher return than traditional peas or lentils (Murray et al. 1987). Both domestic and export markets exist. The introduction of the California cultivar 'UC-5', combined with good market development, led to a developing chickpea industry in northern Idaho in the early

1980's. Two cultivars, 'Lyons', and 'Aztec', were developed and released by the University of Idaho to expand existing markets (Auld et al. 1985). Chickpea is drought tolerant, which is attributed to its deep taproot that can grow as deep as 6.6 ft, and is therefore suitable for the semi-arid conditions of eastern Oregon. Chickpeas can be grown to maturity from March to June. Grain yields of 923 and 1,060 lbs/acre have been obtained by *kabuli* and *desi* chickpeas, respectively (Corp et al. 2004).
Chickpea is susceptible to Ascochyta leaf blight (*Ascochyta rabiei*), a seed-borne disease is that has caused catastrophic losses to this industry in recent years. A self-imposed industry moratorium on chickpea production was enforced in 1988 and 1989 to reduce disease inoculum levels. Adoption of field and seed sanitation standards combined with resistant varieties is necessary for the continued production of chickpeas. The cultivars 'Dwelley' and 'Sanford' developed and released in 1994 by the USDA-ARS in cooperation with Washington State University, the University of Idaho, and Oregon State University have good resistance to Ascochyta leaf blight.

Field Pea
Field pea *(Pisum sativum* L.*)* is the most widely grown cool-season pulse. It has a wide range of uses from dry pulses to succulent fresh peas to edible podded types, and has the highest average grain yield (1,798 lbs/acre). The production of field pea is increasing in Europe, Canada, and Oceania, where the crop is now being produced for animal feed. Domestic production of field pea is estimated at 344,087 acres and includes dry pea, processing pea, seed pea, and Austrian winter pea (NASS 2004).

Winter pea has been grown in northern Idaho for over 50 years, but increased disease and insect pressures threaten continued production. Fall-planted legumes fix N and provide winter cover to help reduce soil erosion (Murray et al. 1987). Winter peas can be harvested for seed, combined with winter cereals for silage production (Murray et al. 1985), grown for green manure to restore depleted soil organic matter (Auld et al. 1982, Sattell 1998), or combined with winter cereals for harvesting as a multiple seed crop (Murray and Swensen 1984). Commercial seed yields have varied from 1,120 to 3,808 lbs/acre during the past 10 years. Improved cultivars (Auld et al. 1983) and improved cultural management recom-mendations (Murray et al. 1984b, Murray et al. 1987) have ensured continued production of winter peas in northern Idaho. Up to 174,100 acres of Austrian peas were grown in the United States in 2003 (NASS 2004).

Field pea is adapted to temperate and sub-tropical environments and is cur-rently produced in both western and eastern Oregon (Sattell 1998).

Faba Bean
Faba bean *(Vicia faba* L.) is a cool-season grain legume that originates from Europe. It can be used for both human and animal consumption and does not contain any toxins. Like lupin, most faba bean varieties possess a large seed size that increases production costs and establishment problems with existing small grain equipment (Kephart et al. 1990). Faba bean seedlings are susceptible to feeding damage by pea leaf weevils (*Sitona lineatus* L.). Several foliar and seed blights indigenous to spring pea production areas will also infect faba beans. Faba bean seed yields have been as high as 2,016 lbs/acre, but inconsistent yields and poor market opportunities have limited production. Winter-hardy faba bean cultivars mature earlier and may produce

more consistent yields under northern Idaho conditions (Kephart et al. 1990).

Evaluation of winter-hardy faba bean cultivars possessing smaller seed size was initiated in the fall of 1988. Faba bean production in the United States is limited. In some areas of the humid northeast and in western Washington and Oregon, the crop is occasionally produced for green forage. Faba bean grows best under cool, moist conditions but does not tolerate heat well. Information on the agronomy of faba bean in Oregon is available (Sattell 1998).

Warm-Season Grain Legumes

Soybean [*Glycine max* (L.) Merr.], peanut (*Arachis hypogaea* L.), common bean (*Phaseolus vulgaris* L.), mung bean [*Vigna radiata* (L.) Wilczek.], and cowpea [*Vigna unguiculata* (L.) Walp] are warm-season pulses better adapted to humid regions. The warm-season pulses are characterized by epigeal ger-mination, a period of rapid vegetative growth, followed by flowering when daylengths become progressively shorter. Because of the flowering requirement, only day-neutral warm-season grain legumes that can tolerate cool seasons can be grown in eastern Oregon.

Soybean is the only warm-season legume that can tolerate cool-season conditions. It is used in the manufacture of edible oils, and in industrial products such as paint, varnish, resins, and plastics. Soybean meal is an important livestock feed. Efforts have been made to grow soybeans in the PNW with limited success. Day-neutral soybean cultivars developed for production in southern Canada expressed delayed flowering and maturation due to cool night time temperatures often experienced throughout the growing season in northern Idaho (Auld et al. 1978). Delayed maturation exposed soybeans to fall precipitation that reduced crop quality. Late maturation also interfered with establishment of fall-sown grain or cover crops. Recent evaluations in eastern Oregon demon-strated that soybeans emerged under cold temperature in spring, and survived the dry and hot summer months (Payne 1999). However, the yields were low (306 lbs/acre). More variety evaluations are needed to identify adaptable varieties. As soybeans require pro-cessing for their use as a feed grain or oilseed crop, market potential in the PNW is limited by the lack of processing facilities.

Oilseeds

Oilseeds tend to be higher-value crops than cereals, and are useful as alternatives in crop production and market diversification. Rapeseed, mustard, safflower, and sunflower seed are considered to be major oilseed cash crops, especially when grain markets are poor.

Rapeseed

Rapeseed or canola (*Brassica napus* L.) is an oilseed crop belonging to the mustard family. Winter rapeseed is sown in the fall and flowers in spring when daylength is increasing. Spring rapeseed is sown early in spring and seed in summer. Winter rapeseed has shown great potential for adaptation to the PNW. Commercial cultivars have been developed with reduced glucosinolate levels in their meals and with improved fatty acid compositions to enhance their industrial and edible oil market values (Auld et al. 1987a, Auld et al. 1987b). Winter rapeseed provides excellent soil erosion control, and reduces disease problems in cereal and legume rotation crops (Kephart et al. 1990, Morra et al. 1996). The agronomy of growing winter rapeseed including cultivar selection, seeding rates, planting dates, row spacings, weed control, soil fertility, and harvesting have been developed in the PNW (Murray et al. 1984a, Wysocki et al. 1991, Brown and Wysocki 2002). Grain yields as high as 3,600 lbs/acre have been produced in eastern Oregon (Wysocki et al. 1991). Spring rapeseed is not competitive with existing rotational crops in the PNW. However, breeding for superior and adaptable spring rapeseed is underway (Brown and Wysocki 2003).

Seed of rapeseed is crushed to produce an oil selected for two distinct uses, edible oil for human consumption (salad and cooking oils, margarine and shortening), or industrial oil for producing synthetic lubricants, varnishes, and plastics. The mealy residue after the oil is extracted can be used as a high-protein livestock feed supplement. When used as a green manure crop, the elevated glucosinolate levels found in the green tissue of specific cultivars suppress soilborne pathogens of cereals, potatoes, and legumes (Vaughn 1999). Winter rapeseed can produce 5.6 to 11.2 tons of dry forage/acre with 9 to 12 percent protein levels. Rapeseed oil could also serve as alternative fuel oil in times of emergency (Peterson et al. 1988). Whole rapeseed is exported to several Asian markets, particularly Japan. Small domestic markets exist for industrial rapeseed shipped to Midwest processors.

Mustard

Mustard (*Brassica juncea* L.) is a cool-season crop that can be grown in a short growing season. Varieties of yellow mustard usually mature in 80 to 85 days whereas brown and oriental types require 90 to 95 days. Mustard, especially the brown and oriental types, has a partial drought tolerance between that of wheat and rapeseed. Moisture stress caused by hot, dry conditions during the flowering period frequently causes lower yields.

Mustard can be grown for its leaves or seed. The leaves of mustard greens are used in salads or eaten fresh, canned, or frozen. Mustard seeds can be crushed to produce edible oil that also can be used for hair oil and lubricants. The oilseed, however, is unpopular in livestock feed and vegetable markets of North America because of its strong flavor. Mustard seed and seed products are used in meats, sausages, processed vegetables, and relishes (Simon et al. 1984). White mustard is generally used for flavoring, and black and brown mustards are generally used for aroma. Mustard seeds are processed to yield mustard flour, from which table mustard and other condiments are made. Prepared English and French mustards are usually made from brown mustard seeds, to which are added capers, white wine, and vinegar (Simon et al. 1984). Mustard is also used medicinally as a folk remedy against arthritis, rheumatism, inflammation, and toothache.

Cultivars of mustard evaluated in the PNW (northern Idaho) were developed in Canada and North Dakota for areas with greater summer rainfall. Experimental yields in the PNW range from 560 to 2,200 lbs/acre (Shelton 1999, Schillinger et al., 2002, Brown and Wysocki 2003). Small contract acreages of spring mustard are grown in the region for the condiment industry. Mustard, like rapeseed, suppresses diseases in cereal-based rotations (Vaughn 1999).

Safflower

Safflower (*Carthamus tinctorius* L.) is an annual oilseed crop adapted to cereal grain areas of the western Great Plains. It is a versatile crop; it can be grown for edible oil, meal, or whole seed for dairy cattle, birdseed, and oil for industrial uses. Because of its high linoleic acid content, safflower commands a premium price among edible oils, and is competitive with canola and olive oil.

Safflower is normally sown in April or early May and blooms and sets seed during periods of declining soil moisture and high temperatures in July and August. Despite the conditions, yields of 2,576 to 3,136 lbs/acre have been obtained by commercial production. Safflower has a deep taproot (7.9 to 9.8 ft), which enables it to extract water from deep in the subsoil. As a result, safflower is the most heat and drought tolerant of the alternative agronomic crops commercially available (Kephart et al. 1990). These properties make safflower suitable for production in eastern Oregon. Safflower has been grown periodically in the PNW for the past 30 years (Auld et al. 1987c, Hang et al. 1982, Murray et al. 1981). In eastern Oregon, safflower grain yields of 544 to 1892 have been obtained (Rasmussen and Smiley 1994; Machado et al. *unpublished data*). In rotation, safflower stubble provides excellent snow trapping for good soil and water conservation in combination with other conservation practices. However, rotations should be carefully planned to reduce the impacts of a dry soil profile following safflower to the subsequent crop. A small number of safflower acres are contracted each year in northern Idaho to serve California crushers. Development of earlier maturing cultivars could improve yield potential of safflower in the PNW.

Sunflower

Sunflower (*Helianthus annus* L.) is the world's second most important source of edible oil. The oil is used for cooking, margarine, salad dressings, lubrication, soaps, and illumination. The oil is also used with linseed and other drying oils in paints and varnishes. Decorticated press-cake is used as a high-protein food for livestock. Kernels are eaten by humans raw, roasted and salted, or made into flour. Poultry and cage birds are fond of raw kernels. Flowers produce a yellow dye. Sunflower is used for fodder, silage, and green-manure crop. Hulls provide filler in livestock feeds and bedding (Duke, *unpublished manuscript*).

Sunflower is grown in semi-arid regions of the world. It is tolerant of both low and high temperatures but more tolerant of low temperatures. Sunflower seeds will germinate at 39°F, but temperatures of at least 48°F are required for satisfactory germination. Seedlings in the cotyledon stage have survived temperatures as low as 23°F. At later stages freezing temperatures may injure the crop. Temperatures less than 28°F are required to kill maturing sunflower plants (Putnam et al. 1990). Sunflower can grow under temperatures ranging from 64 to 91°F, but optimum temperatures for growth are 70 to 79°F. Extremely high temperatures have been shown to lower oil percentage, seed fill, and germination. Sunflower is insensitive to daylength, and photo-period appears not to be critical in choosing a planting date or production area in the temperate regions of North America (Putnam et al. 1990).

Sunflower often produces satisfactory yields under drought conditions detrimental to other crops. This is probably due to its extensively branched taproot that can extract soil water from about 6.6 ft in the subsoil. A critical time for water stress is the period 20 days before and 20 days after flowering (Putnam et al. 1990). The drought tolerance of sunflower, combined with its tolerance for low and high temperature and daylength insensitivity, makes it suitable for production in eastern Oregon. Grain yields in recent trials conducted in eastern Oregon ranged from 400 to 1,200 lbs/acre (Wysocki, *unpublished data*; Machado et al., *unpublished data*). Commercial sunflower hybrids can be grown in the warmer dryland areas of northern Idaho (Murray et al. 1978, Murray et al. 1986). Late maturity, limited production experience, lack of suitable equipment, and dry, hot summers have limited the seed production potential of sunflowers. Sunflower silage production has been more successful. Dryland sunflower silage yields adjusted to 70 percent moisture content have averaged nearly 30 metric tons/ha at Moscow, Idaho from 1978 to 1980. Feeding trials have shown sunflower silage is acceptable forage for growing beef steers and dairy heifers, and for dairy cows in mid to late lactation (Kephart et al. 1990).

Cereals

Cereals also can be included in wheat-based rotations. Some cereals tolerate drought more than wheat and can utilize water in different rooting zones. Cereals that may be included in rotation include durum wheat, barley, triticale, rye, oats, and sorghum. Other alternative wheat cereals that need to be evaluated for adaptability to conditions in eastern Oregon include durum wheat, spelt wheat, einkorn, emmer, and kamut.

Durum Wheat

Durum wheat (*Triticum turgidum* L.) has an amber-yellow endosperm (from which semolina is produced) and unlike the white endosperm of common wheat, pasta from durum semolina is amber colored. The flavor and cooking qualities of durum pasta are superior and durum wheat is preferred for the production of pasta products, such as spaghetti and macaroni, and for couscous, the staple food in North Africa (Small 1999).

Durum is adapted to dry climates, with hot days and cool nights, and does well under dry conditions. About 8 percent of the world's wheat production is durum wheat. The leading producers of durum wheat are the European Union, Canada, and the United States. In North America, durum wheat is most suited to western North Dakota and southern Saskatchewan. Durum wheat, as a crop, compares to common wheat much as alternative and new crops do. It is a relatively high-value commodity with a more stable future in Canada than common wheat. The increasing popularity of pasta with stronger and less elastic gluten has increased the interest in durum wheat. Available varieties in eastern Oregon are spring types whose yields are poor. Winter types have been developed by the Oregon State University (OSU) breeder, Dr. J. Peterson, but they lack winter hardiness. More work to develop high yielding and winter hardy durum varieties is needed.

Spelt wheat

Spelt wheat (*Triticum spelta* L.) is referred to as "covered wheat" since the kernels do not thresh free of the glumes or the lemma and palea when harvested. Spelt wheat is used primarily as an alternative feed grain to oats and barley. Food manufacturers in the United States have begun to use spelt to meet the nation's increasing demand for pasta and high fiber cereals. Spelt also can be used in flour and baked goods to replace soft red winter wheat. Spelt is generally more winter hardy than most soft red winter wheat varieties, but less winter hardy than most hard red winter wheat varieties. There is very little evidence that any spring types of spelt exist. Several thousand acres are cultivated in the United States.

Einkorn

Einkorn (*Triticum monococcum* L.) is also a "covered wheat". Einkorn flour is high in protein, ash, carotene content, and has small flour particle size when compared to the modern bread wheats. Dough characteristics of the einkorn accessions are significantly inferior to the modern wheats. The gluten strength is similar to that of soft wheats, but it remains sticky, with a low water retention capacity (Stallknecht et al. 1996). Einkorn is cultivated in harsh environments and on poor soil. The protein and yield of einkorn is equal to or higher than barley and durum wheat when grown under adverse growing conditions.

Emmer
Emmer (*Triticum dicoccum* L.), like spelt and einkorn, is a "covered wheat". In the early 1900's emmer was grown throughout the Midwest and western United States. Emmer yields exceeded yields of barley, oats, and wheat cultivars in years with less than favorable growing conditions, and produced equal or lower yields when growing conditions were more suitable for cereal production (Stallknecht et al. 1996). Emmer is grown for grain that is used as cattle feed, replacing either oats or barley in feedlot rations. Protein levels of emmer are higher than oats or barley. Breads produced from whole grain flour of emmer are heavy textured.

Kamut
Kamut (*Triticum turgidum* L.) kernels are twice the size of wheat kernels and are characterized by a distinctive hump shape. Kamut wheat is a specialty cereal that is marketed primarily through health food outlets. Over 70 processors list more than 100 Kamut products in the United States and Canada under regulation of the Kamut Association of North America (KANA), and the Kamut Association of Europe (KAME). Kamut products include whole grain flour, breads, hot and cold cereals, pastas, and chips, in addition to a green plant dehydrated product. Kamut grains have higher protein when compared to wheat grown under similar conditions. Kamut products made from whole grain flours have a mild, nutty flavor. Individuals who experience certain types of allergic reactions to products made from common wheat are able to eat Kamut products (Stallknecht et al. 1996).

Triticale
Triticale (×*Triticosecale* Widdmark) is the stabilized hybrid of wheat (*Triticum*) and rye (*Secale*). Triticale can be successfully produced in areas where wheat performs poorly, particularly on cold and infertile soils, extremely sandy soils, soils with high levels of boron, salty soils, acidic soils, manganese-deficient soils, and dry soils. The milling and baking quality of triticale grain is inferior to bread-making wheat and to durum wheat for macaroni, but it is often considered superior to rye. Globally, triticale is used primarily for livestock feed. In Mexico, triticale is used mostly for whole-grain breads and tortillas. In the United States, triticale is grown mostly for forage, but there is a small market for pancake mixes and crackers. Ethanol plants will pay a premium for triticale over barley since it has more starch and no hull, making alcohol production more efficient. Winter triticale is a higher-yielding, earlier-maturing alternative to spring triticale for short-season areas. In Oregon, winter triticale yields range from 67 to 190 bu/acre (Karow 2000a, 2001a, 2002).

Barley
Barley (*Hordeum vulgare* L.) is the fourth most important cereal in the United States. About 50 percent is used for livestock fodder and 37 percent for the brewing industry (80 percent for beer, 14 percent distilled alcohol, and 6 percent malt syrup; Duke, *unpublished manuscript*). Barley flour can be used instead of wheat to make bread.

Barley is widely cultivated in all temperate regions of the world and in the high mountain regions of the tropics. It is reported to tolerate alkali, aluminum, disease, drought, frost, grazing, hydrogen fluoride, low and high pH, heat, insects, nematodes, smog, sulfur dioxide, and waterlogging (Duke 1978). Barley has a shorter growing season than wheat or oats and can be grown at higher latitudes. Barley is not particularly winter-hardy, so most is grown as a spring crop. Average optimum temperature for growth is 60–63°F. Barley is grown on soils that are too light or otherwise unsuitable for wheat cultivation and does well on light or sandy loam soil. Barley can be grown following winter wheat in eastern Oregon. In recent variety evaluations, spring barley yields ranged from 1,074 to 5,030 lbs/acre (Karow 2000b, 2001b, 2003).

Oats

Oats (*Avena sativa* L.) are cultivated for the grain, hay, and pasture. Oats are used for cereals, cakes, biscuits and other pastries, for making oat flour, and as a source of oil. Oat straw is used as energy fodder, but mostly for bedding purposes because of its excellent absorbent qualities (Duke, *unpublished manuscript*). In the United States, oats are used for pasture, silage, and hay, and especially as a cover crop to protect soil on marginal land subject to erosion, and as a nurse crop to protect newly planted forages.

Oats grow under moist to very dry conditions. The crop can tolerate annual precipitation of 8 to 72 inches, annual temperatures of 41 to 79°F, and pH of 4.5 to 8.6 (Duke, *unpublished manuscript*). Winter oats evaluated in Oregon produced from 1,568 to 4,457 lbs/acre (Karow 2000a) and spring oats produced from 540 to 4,440 lbs/acre (Karow 2003).

Rye

Rye (*Secale cereale* L.) is grown for the grain that is used to make flour, the importance of which is second only to wheat. The grain also is used to make Canadian and United States whiskies. Roasted grains can be used to substitute for coffee. Rye grains can be used for livestock feed when mixed with other cereals. The crop also can be grown as pasture and can be used as green manure and cover crop, hay, and silage with crimson clover. Rye straw is used as packing material for nursery stock, bricks and tiles, for bedding, paper manufacture, archery targets, and mushroom compost (Duke, *unpublished manuscript*).

Rye is an extremely hardy plant, and is often grown where other grains will not grow. The crop grows well on infertile, submarginal areas and on sandy soils. Rye can grow in areas with annual precipitation that ranges from 8.8 to 70 inches and annual temperatures of 40 to 70°F. Unfortunately rye is now considered a weed in most of eastern Oregon.

Buckwheat

Buckwheat (*Fagopyrum esculentum* Moench) is native to temperate East Asia, and has proven itself to be widely adapted around the world. Japan is the major importer of buckwheat. In Japan, buckwheat flour is employed in combination with wheat flour to prepare buckwheat noodles (soba), a traditional dish. Ground leaves are sometimes added to the buckwheat flour, producing a green noodle. Buckwheat also can be grown as a green manure crop, companion crop, cover crop, and as a source of dark buckwheat honey. The grain and straw can be used for livestock feed, but the nutritive value is lower than that of cereals. The protein in buckwheat flour is of exceptional quality, containing a high amount of lysine, which is deficient in cereals. The groats (dehulled seed) or flour are also used to make other foods. Buckwheat flour is low in gluten content and is usually mixed with wheat flour for bread, pancakes, noodles, and breakfast cereals. Groats and grits (groat granules) can be used for porridge and other breakfast cereals. Dehulled groats can be baked or steamed and eaten as a vegetable like rice, or used in appetizers, soups, salads, breads, and desserts (Small 1999).

Buckwheat is a broadleaf cereal marginally adapted to the warmer dryland cereal production areas of northern Idaho (Auld et al. 1986). Buckwheat is more drought-tolerant than many other alternative crops, but is sensitive to frosts. Buckwheat can be used as a cover crop or green manure crop (Sattell 1998). Ways to increase its productivity and its economic value should be investigated.

Grain Sorghum

Grain sorghum (*Sorghum bicolor* L. Moench) is a warm-season summer annual with poor adaptation to the winter rainfall cycle and cooler temperatures of the PNW. The earliest maturing hybrids obtained from Midwestern states have failed to produce mature seed in northern Idaho (Kephart et al. 1990). Sorghum is a drought-tolerant crop and may do well in the PNW if varieties that can germinate under cooler conditions are developed. In eastern Oregon, grain yields of 267 to 1,047 lbs/acre have been obtained (Payne 1999).

Crops with Pharmaceutical and Industrial Uses

During the last decade, more agronomic research has been directed at increasing the production of new and alternative crops and their by-products for industrial and pharmaceutical use. Some of the under-exploited temperate industrial and fiber crops include meadowfoam, flax, crambe, kenaf, lesquerella, cuphea, euphorbia, vernonia, grindelia, hesperaloe, hemp, and sunnhemp.

Meadowfoam

Meadowfoam (*Limnanthes alba* Hartw.) is a winter annual that originates from and is adapted to the PNW. Meadowfoam development was made possible by USDA efforts in the early 1950's. Meadowfoam is cultivated for its rare oil, 95 percent of which is made up of C:20 or C:22 monoene or diene fatty acids (Kleiman 1990). Such fatty acids can be used in cosmetics, specialty lubricants, and polymers (Carlson et al. 1992). The only active crop research program is at OSU in cooperation with the OMGA and Fanning Corp. The crop is native to western Oregon (where it is grown in the Willamette Valley) and northern California. Meadowfoam should be well adapted to areas with cool soils at planting, cool and moist weather during vegetative growth, and warm, dry weather at harvest. The crop should be evaluated for suitability to eastern Oregon conditions.

Flax

Flax *(Linum usitatissimum* L.) was grown in Oregon in the 1940's (Hurst et al. 1953) but was eliminated in the 1950's by the reintroduction of European flax, the increase in cotton use in textiles, and the development of petroleum-based fibers (nylon) (Roseberg 1996). Interest has been recently revived mainly due to restrictions on stubble burning from grass seed production; these restrictions have caused problems in terms of weed control, insect, and disease cycles (Roseberg 1996). Inclusion of flax (a dicot), in grass-based rotations would provide disease breaks and allow use of alternative herbicides while providing a cash crop for growers. Flax produces fiber in stems that is used in making fine linens for clothing, draperies, and furniture. Medium fibers are used for canvas and geo-textiles, while short fibers are used for paper and sacking. Oil (linseed) is produced in flax seeds.

Flax can successfully be grown in western Oregon. The crop grows in areas that have cool, moist spring weather followed by warm summers, conditions that also prevail in eastern Oregon. Oregon statewide average yields from 1925 to 1951 ranged from 1,456 to 5,712 lbs/acre dry matter (Hurst et al. 1953). Grain yields obtained from 2002 and 2003 in eastern Oregon ranged from 200 to 400 lbs/acre (Machado, *unpublished data*). Higher yielding varieties should be developed and the agronomic practices should be improved.

Crambe

Crambe (*Crambe abyssinica* Hochst.) is a cool-season annual originating from Ethiopia. The crop has been raised in large areas in North Dakota. The oil from crambe seed is high in erucic acid that is used to manufacture synthetic lubricants and plastics. Crambe yields have averaged 2,016 to 2,464 lbs/acre in trials conducted at Moscow, Idaho in 1983 and 1984. Average seed oil content has been 35 percent. Existing cultivars lack uniform maturity, edible meal characteristics, and they shatter easily. Commercial oilseed crushing facilities for crambe are not currently available in the region.

Kenaf

Kenaf (*Hibiscus cannabinus* L.) was first cultivated in Africa and made its way to the United States in the 1940's largely through the efforts of the USDA's Search for New Pulp Fibers program (Rosenburg 1996). Kenaf fibers are used for making rope, sacking, twine, and matting. The fibers could potentially be used for newsprint, carpet backing, and as a composite for boards or other structural materials. The newsprint market in the United States is huge but kenaf must compete with wood pulp in this market. It is, however, cheaper to process kenaf than wood.

Highest yields of kenaf can be produced when mean daily temperatures are between 72° and 86°F, monthly precipitation between 3.6 and 11 inches and relative humidity (RH) between 65 and 85 percent (Rosenburg 1996). Some work on kenaf has been done in southern Oregon where average yields of 6,720 and 13,440 lbs/acre stem dry weight were obtained in the Willamette Valley and the Rogue Valley, respectively. Experiments to evaluate kenaf in eastern Oregon should be conducted.

Lesquerella

Lesquerella (*Lesquerella fendleri* L.) is a perennial plant of the Brassicaceae family that is produced as an annual for seed oil high in hydroxy fatty acids. The oil is used for specialty lubricants, heavy-duty detergents, inks, and coatings (Roseberg 1996). Lesquerella is well adapted to semi-arid locations and may be adapted to the PNW. It is planted in October and seeds develop between March and May. Lesquerella is not being produced commercially. Some small plot studies have been done in southwestern Oregon and plot yields ranged from 504 to 1,120 lbs/acre.

Cuphea

Cuphea (*Cuphea spp.*) is an oilseed crop that is native to Mexico and Central and South America. Many cuphea species have oils rich in capric, lauric, caprylic, myristic, or other medium chains fatty acids (MCFAs) (Knapp 1990, Roseberg 1996). Lauric acid is used in soaps and detergents and capric, caprylic, and myristic acids are potentially useful in industrial or nutritional applications. Cuphea is not produced commercially. The United States relies on imports of coconut and African oil palm that are rich in MCFAs (Knapp 1990, 1993). Almost all Cuphea species are wild, and seed shattering and dormancy are major obstacles to domestication (Knapp 1993). Efforts are underway to domesticate Cuphea using non-shattering cultivars (Knapp 1993). Warm weather with sufficient moisture favors vegetative growth. Cuphea is likely to grow in the Midwest and northwestern United States.

Euphorbia

Euphorbia (*Euphorbia lagascae* [Spreng]) is an herbaceous annual plant native to Spain. The seeds are potentially a source of epoxy acid that is used for adhesives, plasticizers, industrial coatings, varnishes, and paints. Lines with slightly earlier maturity may have potential in North Dakota. (Berti and Schneiter 1993). There is no commercial production at present. Work done at Corvallis and Medford, Oregon (1993-1995) indicate that seed yields from 1,187 to 3,136 lbs/acre can be obtained. Results from these studies indicate that euphorbia can be successfully grown in the PNW. The major problem with euphorbia is its violent seed shattering habit that makes it difficult to harvest the seed. Recently, chemically induced, non-shattering mutants have been developed in Spain.

Vernonia

Vernonia (*Vernonia galamensis* L.) or ironweed is one of 6,500 wild plant species screened by the USDA for production of desirable seed oils. This potential oilseed crop is native to eastern Africa. It is an annual herbaceous plant of the Compositae (Daisy) family. Vernonia seed contains about 40 to 42 percent oil of which 73 to 80 percent is vernolic acid. Vernonia can be used for epoxies for manufacturing adhesives, varnishes and paints, and industrial coatings. The plant could also serve as a natural source of plasticizers and stabilizers (binders) for producing polyvinyl chloride (PVC plastic), which currently is manufactured from petroleum. Vernonia is not produced commercially in the United States. Very little is known about vernonia's agronomy. The plant is fairly drought tolerant but requires a long season. Production areas would likely include much of the temperate United States.

Grindelia

Grindelia (*Grindelia camporum* [Greene]) is native to the San Joaquin Valley, Sacramento Valley, and adjacent Coast Range of central California. It has the ability to grow and flower primarily in the hot, dry summer months. Resins from various species of grindelia have been patented for use in adhesives, rubber, coatings, textiles, and polymers. Grindelia resins could provide a potential alternative source of diterpene resin acids for use in inks, sizings, adhesives, and other naval stores products. Naval stores is a generic term for a large class of chemicals that include turpentine, fatty acids, rosins, and their derivatives. Rosin is a complex mixture of diterpene resin acids that have wide and diverse industrial applications. Domestic supply of high-quality wood rosin, which is extracted from aged pine stumps, has disappeared. The recovery of gum rosin by tapping living pine trees is very labor intensive, and production within the United States has declined to nearly zero. The United States' market has required more than 1.1 billion lbs of rosin in the recent past (Hoffmann and McLaughlin 1986). Grindelia is not produced commercially in the United States. A few trials were conducted in southern Oregon from 1992 to 1994 and 4,144 to 4,928 lbs/acre of resin were obtained (Roseberg 1996). Grindelia is likely to grow in the PNW.

Hesperaloe

Hesperaloe (*Hesperaloe funifera* [Koch]) is a native of the Chihuahuan Desert region of northern Mexico. It produces strong fibers (fiber bundles) that are used in northern Mexico for cordage products. The fibers have a potential use in paper-making. Both *H. funifera and H. nocturna* produce long fibers that are comparable to those of softwoods in their length but are less than half as wide. The fibers of hesperaloe produce paper with exceptional tensile and tear strength that could be used in specialty papers with high-strength requirements, such as currency papers, bible papers, tea bags, and filters. The fibers also can be blended with other fibers to increase the strength and improve the texture of a variety of paper products, including writing papers, tissue and towel products, and papers manufactured using secondary (recycled) fiber (Roseberg 1996).

Hesparaloe is not grown commercially in the United States. Areas of its adaptation are not yet known. Small plot studies have been done in southern Oregon from 1992 to 1994. The crop survived the conditions in southern Oregon and produced about 10,800 lbs/acre fresh weight (Roseberg 1996).

Sunn Hemp

Sunn hemp (*Crotalaria juncea* L.) produces a bast fiber similar to kenaf that could be used in pulp and paper applications (Dempsey 1975, Cook and White 1995). The fiber is used in twine, rug yarn, cigarette and tissue papers, fishnets, sacking, canvas, and cordage. Sunn hemp is a legume that is widely grown throughout the tropics as green manure, the dried stalks and hay being used as forage for livestock. Although reported to be poisonous to livestock, seeds are fed to horses in the Soviet Union and to pigs in Zimbabwe.

Unlike kenaf, it is highly resistant to root-knot nematodes and thus can be grown in some areas where kenaf cannot (Cook and White 1995). Sunn hemp is fairly drought tolerant, can grow in marginal soils, and, being leguminous, has low N requirements. Although generally considered to be a tropical or subtropical crop, it is drought resistant and has a wide range of adaptation to soil types.

Conclusions

The detrimental effects of the traditional wheat/fallow rotation that is commonly practiced in eastern Oregon can be alleviated by the introduction of alternative crops that reduce or replace the fallow. The crops briefly discussed above must be further evaluated for their contribution in the diversification of eastern Oregon cropping systems, enhancement of human nutrition, and to rural and regional economies. To introduce alternative crops, preliminary evaluation trials should be conducted to generate sufficient management information to permit pilot production of promising crop species. More extensive research is then conducted for species showing greatest commercial potential. Research is needed to determine how well the new crops perform in conventional and no-till cropping systems, with specific emphasis placed upon (1) planting date, planting depth, and stand establishment; (2) rooting depth and water use; (3) organic matter build-up and soil structure; 4) weeds, arthropod, and disease control, and 5) influence on yield and profitability of the rotations. This information will assist farmers in determining the contribution of alternative crops in cropping systems and provide a database for enhancing the management of alternative crops in both the short and long term. Extension programs should complement research efforts to assure successful production of these crops by area growers. The economic feasibility studies and the search for potential markets should accompany both research and extension efforts.

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ROTARY SUBSOILING TO REDUCE EROSION AND IMPROVE INFILTRATION IN NEWLY PLANTED WINTER WHEAT AFTER SUMMER FALLOW

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Abstract

Water erosion and runoff can be severe due to poor infiltration through frozen soil in the dryland wheat (*Triticum aestivum* L.) production region of the inland Pacific Northwest (PNW), USA. For more than 70 years, farmers and researchers have used various methods of subsoiling to reduce runoff and erosion and to improve infiltration and soil water storage. The practice and equipment have evolved from chiseling continuous open channels across hillslopes to the rotary subsoiler that pits the soil. Farmers often subsoil wheat stubble after harvest, but do not employ this practice on newly-planted winter wheat fields. These fields are especially vulnerable to erosion because of meager residue cover after a year of fallow. A 6-year field study was conducted in eastern Washington to determine the effect of rotary subsoiling in newly-planted winter wheat on over-winter water storage, erosion, infiltration, and grain yield. There were two treatments, rotary subsoiling and control. The rotary subsoiler created one 16-inch-deep pit with 0.98-gallon capacity every 7.5 ft^2. Natural precipitation did not cause rill erosion in either treatment because of mild winters during the study period. Net change in water storage was significantly ($P < 0.05$) improved with rotary subsoiling compared to the control in 2 of 6 years. Grain yield was not affected by treatments in any year or when averaged over years. In 2003, we simulated rainfall for approximately 3 hr at a rate of 0.72 inch/hr on both subsoiled and control plots to determine runoff and erosion responses on frozen soils. Rotary subsoiling reduced runoff ($P < 0.01$) by 38 percent. Rotary subsoiling also significantly reduced erosion ($P < 0.01$) during the 20- to 45-min period after runoff had begun. The total quantity of eroded soils were 0.58 and 1.52 ton/acre for the subsoiled and control treatments, respectively, with inter-rill the dominant erosion process. The average infiltration rate for the control treatment (0.13 inches/hr) was half of the rate for the subsoiled treatment (0.26 inches/hr), at the end of the 3-hr simulation. Rotary subsoiling of newly-planted winter wheat can increase soil water stored over-winter and reduce runoff and soil loss on frozen soils, but the benefit of this practice for increasing grain yield has not been proven.

Key words: frozen soil, runoff, Pacific Northwest, water infiltration

Introduction

The winter wheat–summer fallow system of farming, where one crop is produced every 2 years, has historically proven to be the most reliable and generally most profitable method for growing wheat in the 6- to 14-inch precipitation zone in the inland PNW. However, tillage during fallow to control weeds and inject fertilizer, and preparation of the seedbed is often intensive, (i.e., eight or more tillage operations), and often leaves soil prone to wind and water erosion. When winter wheat is planted into fallow in late summer residue cover is often lacking and, depending on weather conditions and date of planting, winter wheat seedlings contribute as little as 3 percent cover by the first of November and the onset of water erosion events.

Infiltration rates for unfrozen silt loam soils in the region are relatively high. Zuzel and Pikul (1987) reported a 0.59-inch/hr infiltration rate in Walla Walla silt loam (coarse-silty, mixed, mesic Typic Haploxeroll), a representative soil for much of this region where 95 percent of storms have precipitation rates less than 0.18 inch/hr (Williams et al. 1998). Soil freezes regularly to a depth of 4 inches, and occasionally to 16 inches (Papendick and McCool, 1994). The most severe erosion generally occurs when snowmelt or rain occur on thawed soil overlying a subsurface frozen layer (Zuzel et al. 1982, Zuzel 1986). Erosion occurs predominately as rills (McCool et al. 1982) with smaller contributions by sheet erosion, and soil suspension movement below frozen soil surfaces and above plow pans. Zuzel and Pikul (1987) and Pikul and Zuzel (1993) demonstrated that infiltration into frozen silt loam soil can approach zero, depending on the depth of freezing and soil water status (Willis et al. 1961). Combined, these events and conditions lead regularly to losses of 2.2 to 8.9 ton(s) of soil/acre/year, and occasionally up to 89.2 tons of soil/acre/year, in the approximately 2.22 million acres planted to winter wheat following summer fallow in this region (USDA 1978, Smiley 1992, McCool et al. 1993).

Most farmers pursue the goal of limiting runoff and associated erosion from frozen soils. Unfortunately, even management practices that combine residue retention, contour tillage and planting, and terraces often do not prevent erosion (Saxton et al, 1981). To reduce erosion, farmers have used various methods of chiseling or subsoiling since the 1930's (Spain and McCune 1956). Subsoiling, also known as ripping in France and chiseling in the United States and Canada, is the creation of deep channels, without inversion, using knife-like shanks that are pulled through the soil to create continuous grooves 30- to 24 inches deep and spaced 24- to 59-inches apart. The desired result is the capture of snowmelt or rain and improved infiltration through frozen soil and/or tillage pan to enhance soil conservation, soil water storage, and wheat grain yield. For these reasons, many farmers chisel recently harvested wheat stubble (i.e., start of the fallow cycle) to increase over-winter capture of water for winter wheat planted the following year.

A number of subsoiling techniques have been evaluated in recent years that aim to capture rain and snow melt in newly planted winter wheat fields when plants are still in the seedling stage of development. Pikul et al. (1992) chiseled continuous grooves in the soil to a depth of 8 inches, adjusting the spacing between shanks to capture runoff from a range of storms and soil conditions. When depth of freezing is greater than depth of chisel or shank, the effectiveness of subsoiling is reduced or lost (Pikul et al. 1992, Pikul et al. 1996).

Schillinger and Wilkins (1997) used shanks in a 2-year experiment to create continuous 10- to 25-inch-deep channels spaced 12 or 20 ft apart. One winter was relatively dry, the second relatively wet. Erosion was reduced in the subsoiled vs. control plots during both years. They also recorded increased soil water content to a depth of 6 ft, 3 ft down-slope from the tillage channels. In both years, wheat grain yield was reduced in the rows most disturbed by the chisel shank, but was increased in adjacent rows. On a whole-plot basis, there were no differences in grain yield between subsoiled and control treatments in either year. Similarly, Pikul and Aase (1999, 2003) used a paratill to break up a tillage pan in a sandy loam soil, and chiseled narrow channels to a depth of 12 inches. Infiltration and soil strength were improved up to 2.5 years later, after deep chiseling, but root-zone soil water and grain yield showed no response to the treatment. Tillage following deep chiseling reduced infiltration and erosion-control benefits. Pikul and Aase (2003) found that subsoiling a sandy loam soil with paratill to a depth of 12 inches improved infiltration, but water drained to below the rooting depth of wheat. Movement of water below the root zone, loss of nutrients, and possible groundwater contamination are concerns on shallow soils (Pikul and Aase 1999).

Farmers have shown little interest in chiseling continuous channels on the contour in newly planted wheat fields because 1) too many wheat plants are destroyed, negating any increase in grain yield potential even though more water may be stored in the soil; and 2) the likelihood of continuous channels concentrating flow. Continuous channels should be perfectly on the elevation contour to prevent concentrating flows and erosive force at low points (Saxton et al. 1981). Additionally, channels chiseled into dry soil often immediately refill with dry soil (Saxton et al. 1981, Pikul et al. 1996). To avoid this problem, Wilkins et al. (1991) and Wilkins and Zuzel (1994) chiseled winter wheat fields after the soil had frozen using a shank with attached rotary pitter to create infiltration channels with pits. The purpose of the pits was to disrupt the continuity of the groove. The implement did not consistently penetrate the frozen soil. Ponded infiltration rates in plots treated with the implement were greater than rates from control plots. Despite the appearance of some wheat disease, yields were not depressed (Wilkins and Zuzel 1994).

The purpose of rotary subsoiling is to create pits that cause minimum damage to wheat seedlings, eliminate concentrated flow with continuous channels, and reduce power requirements associated with pulling shanks through the soil. Our objectives were to determine if rotary subsoiling 1) reduced runoff and erosion, 2) increased soil water stored over-winter, and 3) affected winter wheat grain yield.

Materials and Methods

Field layout

Six on-farm experiments were conducted near Harrington, Ritzville, Wilbur, and Lind in Lincoln and Adams counties in east-central Washington, from crop years 1997 through 2003 (Fig. 1). The study was not conducted in 2000-2001 because of early snow. Soils at all sites were deep and well-drained silt loams, formed in loess, with slopes ranging from 10 to 40 percent (Table 1) (Stockman 1981, Lenfesty 1967). Winter precipitation generally does not fill the soil profile. Experiment sites were identified by the farmer cooperators as historically prone to water erosion. Individual plot size ranged from 39 to 85 ft wide and 151 to 190 ft long, depending on the available slope area. Experimental design during all years was a randomized complete block with six replications of two treatments: rotary subsoiling and control.

A 2-year rotation of winter wheat summer fallow was practiced at all sites during all years of the study. Tillage during fallow generally consisted of chiseling stubble in the fall, primary spring tillage with either a tandem disk or two passes with a field cultivator plus attached harrow, a separate operation to inject aqua NH_3-N with shanks, and two to four rodweedings (a rotating 1-inch^2 rod) to control weeds and break capillary continuity in the soil to retard the upward movement of liquid water in summer fallow during dry summer months.

Winter wheat was planted from early-to-mid September with a John Deere HZ™ deep-furrow drill on 16-inch row spacing until crop year 2000, after which a John Deere hoe drill with 10-inch row spacing was used.

Uniform stands of winter wheat were achieved each year of the study. Plots were rotary subsoiled each fall following wheat emergence and sufficient rainfall so that the pits did not collapse and fill with dry soil.

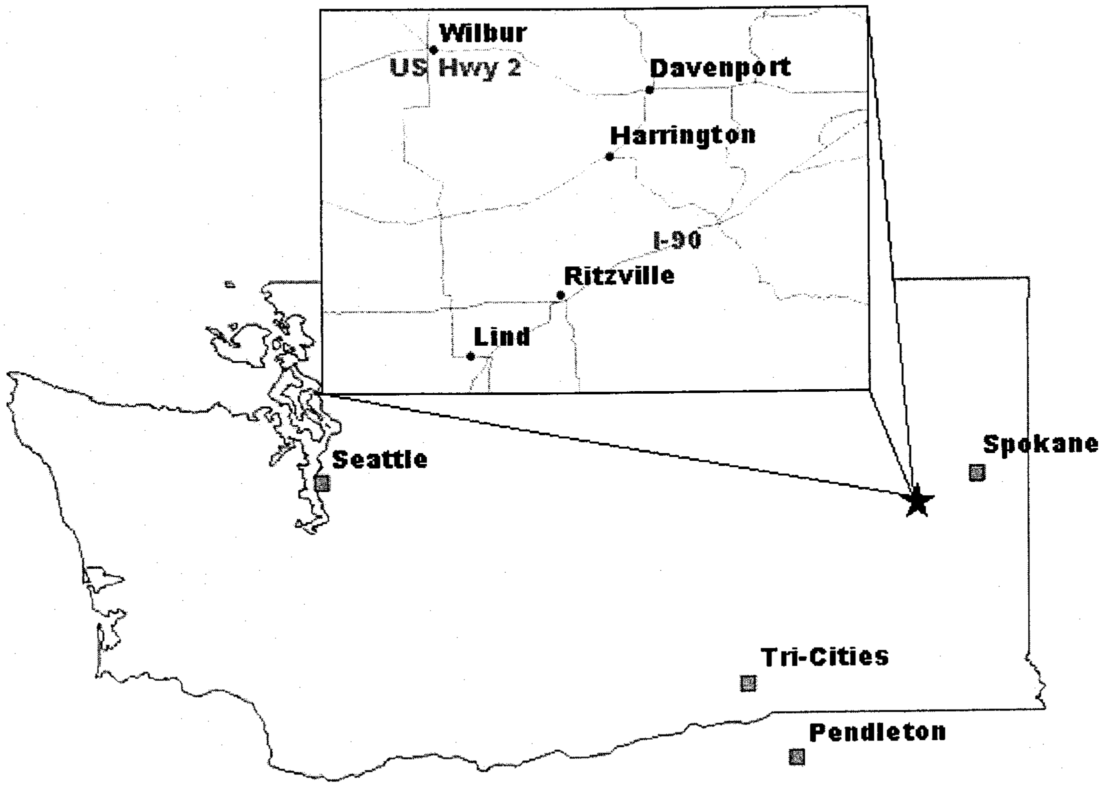


Figure 1. Rotary subsoil research plots were established near the towns of Wilbur, Harrington, Ritzville, and Lind, Washington during 6 years.

Table 1. Location, soil type, precipitation, frost-free days, and mean annual air temperature during 6 years of rotary subsoiler field experiment sites in eastern Washington.

Crop year	Location	Soil type[1]	Annual precipitation (inches)	Frost-free season (days)	Mean annual temperature (°F)
1997	Wilbur	Bagdad silt loam (coarse-silty, mixed, superactive, mesic Calcic Argixerolls)	12.5	110 – 150	49
1998	Ritzville	Ritzville silt loam (coarse-silty, mixed, mesic Calcidic Haploxeroll)	11.2	120 – 160	49
1999	Lind	Shano silt loam (coarse-silty, mixed, superactive, mesic Xeric Haplocambids)	9.6	140 – 170	50
2000	Harrington	Bagdad silt loam and Endicott silt loam (coarse-silty, mixed, mesic Haplic Durixerolls)	13.0	110 – 150	49
2001	No study, early snow				
2002	Harrington	Bagdad silt loam Endicott silt loam	13.0	110 – 150	49
2003	Harrington	Bagdad silt loam Endicott silt loam	13.0	110 – 150	49

[1] Lenfesty (1967), Stockman (1981).

The "shark's tooth" rotary subsoiler (Fig. 2) created 1 16-inch-deep by 2-inch-wide pit every 8 ft^2 (5,781 pits/acre), each pit with 1-gal capacity. The rotary subsoiler was pulled along the contour of the slope by a crawler tractor and was lifted out of the soil when crossing control plots.

Figure 2. Rotary subsoiler in transport position.

Soil water, erosion, and grain yield measurement

Soil volumetric water content in the 12- to 71-inch depth was measured in 6-inch increments by neutron thermalization (Hignett and Evett 2002). Volumetric soil water content in the 0- to 12-inch depth was determined from two 6-inch core samples using gravimetric procedures (Top and Ferre 2002). Three access tubes were installed in each plot, i.e., 36 access tubes. Neutron probe access tubes were placed 12 inches down-slope from a pit created by the rotary subsoiler. Access tubes were placed in the same general lateral locations in the control treatment. Rill erosion was measured (McCool et al. 1976) in all plots during every year. Winter wheat grain yield was measured by harvesting the grain from plants in a swath through each plot with a commercial combine with 30-ft-wide cutting platform and auguring grain into a weigh wagon.

Simulated rainfall and ponded infiltration

The research site was located 7 mi southeast of Harrington (47° 23'45"N, 118° 11'00"W) at an elevation of 2,200 ft. We simulated rainfall in February 2003 on plots that had received approximately half of the expected annual precipitation, on rotary subsoiled and control plots with 18 percent slope with an east, southeast aspect, at a rate of 0.71 inch/hr. Precipitation collected from a metal-roofed building was used for rainfall simulation. Rainfall was simulated using the Pacific Northwest Rainfall Simulator (Williams et al. 1998), onto areas 6.6 ft wide by 32.8 ft long (215 ft^2). The temperature of the water used for rainfall and the air temperature inside the simulator covers were recorded to assure consistent ambient conditions across treatments. Simulation continued for 120 minutes after runoff began. There were four replications in the simulated rainfall measurements of plot runoff and erosion. Four simulator modules rained on four plots simultaneously, two on control plots and two on subsoiled plots. Simulators used on the control treatment during the first set of four plots were used to rain onto subsoiled treatment during the second set. Time to ponding, time to runoff, and runoff in 5-minute intervals for 120 minutes were recorded. Time to fill 1-quart bottles with runoff was recorded and the bottles were weighed, dried at 221°F for 24 hr, then reweighed to determine runoff rate and eroded mass. Infiltration was calculated as infiltration = precipitation – runoff. Residue cover was measured using a modified point frame method (Floyd and Anderson 1982).

Average pit capacity and infiltration rate were determined on day two of rainfall simulations. Thirteen rotary subsoiler pits were randomly chosen and ponded infiltration was measured as follows: a pit was quickly filled with water to near overflow, and the volume of water used and initial time recorded; when the water level dropped approximately one inch, the pit was refilled, and the water volume and time recorded again; the refill procedure was conducted twice. Ponded infiltration rate was calculated for all three refills. The time between the refills averaged 3 minutes. The results from the thirteen pits were averaged to obtain an estimate of pit volume and infiltration rates at 3, 6, and 9 minutes after onset of ponding.

Data analysis

Analysis of variance was conducted for 1) net gain in soil water content in the 6-ft soil profile from the time experiments were established in November or December until mid-March, and 2) winter wheat grain yield. Treatments were considered significantly different if $P < 0.05$. Data analysis for runoff and infiltration from simulated rainfall was performed using the Mixed Models statement in SAS (1998). Least squares means separation tests were conducted on the response variable if the type-three mixed effects were significant ($P \leq 0.10$).

Results and Discussion

Natural erosion, soil water storage, and wheat grain yield

Winters were generally mild throughout the study period and no measurable rill erosion occurred in any year in either rotary subsoiled or control plots. However, sediment was observed to have partially filled some of the pits at Wilbur in 1997 and at Ritzville in 1998.

Net gain in over-winter soil water was significantly greater in rotary subsoiled plots compared to the control at Lind in 1999 and at Harrington in 2000 (Table 2). This finding suggests that some runoff did occur in control plots, probably when the soil surface was frozen although no rill erosion was observed. Averaged over the 6-year study period, net over-winter soil water gain with rotary subsoiling was not different than for the control (Table 2). Winter wheat grain yield varied widely among sites and years, but there were no differences in grain yield between treatments in any year or when analyzed over years (Table 2).

Table 2. Over-winter net gain in soil water and winter wheat grain yield during 6 years as affected by rotary subsoiling newly planted winter wheat fields. Crop rotation is winter wheat–summer fallow.

		Net gain in soil water			Grain yield		
		Rotary subsoiled	**Control**	**Sig.**[1]	**Rotary subsoiled**	**Control**	**Sig.**[1]
Crop Year	**Location**	inches			bu/acre		
1997	Wilbur	7.68	7.56	ns	74	74	ns
1998[2]	Ritzville	0.71	0.59	ns	55	58	ns
1999	Lind	1.57	1.02	**	22	25	ns
2000	Harrington	4.72	3.78	*	98	97	ns
2002[3]	Harrington	3.46	2.95	ns	57	56	ns
2003	Harrington	4.96	5.55	ns	44	46	ns
6-year avg.	All locations	3.86	3.58	ns	58	59	ns

[1]ns = no significant differences at $P < 0.05$. *, ** Significant differences at the 0.05 and 0.01 levels, respectively.
[2]Plots were established in December after considerable precipitation had already occurred, thus the low values for net gain in soil water in 1998.
[3]The experiment could not be conducted in the 2001 crop year due to early snow cover.

Simulated rainfall

Ground cover in rainfall simulation plots was approximately 80 percent in both treatments and consisted of old wheat stubble and young wheat seedlings (Table 3). Surface soil was lightly frozen to a depth of 2 inches, and had gravimetric soil water content of 30 percent. The total simulation time for each plot was 3 hr, during which 2.13 inches of rainfall was applied. Total simulated rainfall was approximately twice the long-term average accumulated precipitation for the month of February for the site (WRCC 2004) and represents a 24-hr storm expected once every 75 years. Average temperature of simulated rainfall was 33°F. Air temperature inside the rainfall simulator covers ranged from 23°F in the morning to 59°F at the end of simulation in the afternoon, when small pockets of frozen soil could still be found.

Table 3. Percent ground cover provided by wheat stubble and winter wheat seedlings in control and rotary-subsoiled treatments at the time of rainfall simulation at Harrington in 2003.

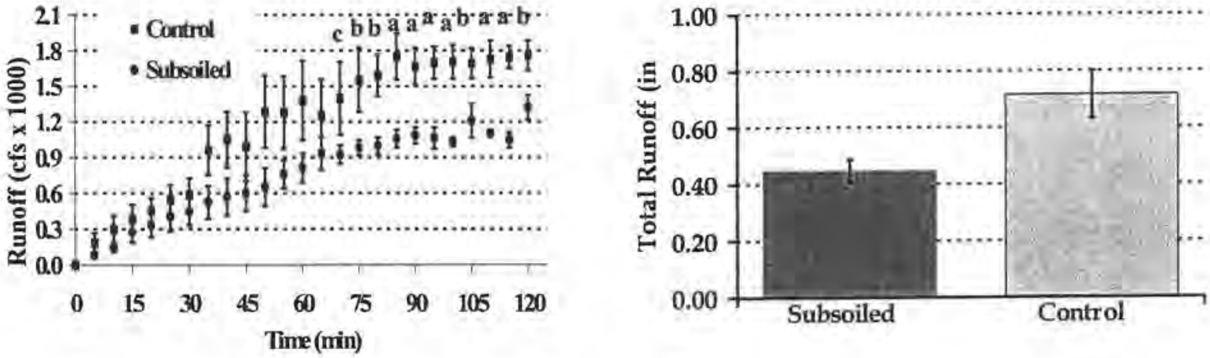
	Control	Subsoiled
Wheat stubble	**48.5 (5.2)** [1]	**53.1 (4.9)**
Wheat seedlings	**36.4 (7.9)**	**26.9 (5.8)**
Total cover	**84.9 (3.1)**	**80.0 (3.6)**
Bare soil	**15.1 (3.1)**	**20.0 (3.6)**

[1]Values in parenthesis are standard error.

Runoff and infiltration

Time to ponding in both treatments occurred within 10 minutes and average time to runoff was 50 minutes after onset of rainfall simulation. There were no significant differences between treatments for either time to ponding or time to runoff. The rotary-subsoiled treatment produced runoff at significantly ($P < 0.01$) lower rates than control treatment, after 70 minutes of simulation (Fig. 3a). The total runoff was 38 percent lower in the rotary-subsoiled treatment than the control treatment (Fig. 3b). At the end of simulation, infiltration rate approached steady state of 0.13 inch/hr in the control treatment, just half of the 0.25 inch/hr in the subsoiled treatment.

The average capacity of the pits was 0.98 ± 0.11 gallons (mean ± standard error), equivalent to a rainfall of 0.21 ± 0.02 inches falling onto the contributing area of the pit and running into it. In addition to detaining runoff, the pits create infiltration galleries. The average ponded infiltration rate for subsoiled pits was 0.72 ± 0.02 inches/hr after three minutes, 0.59 ± 0.10 inches/hr between three and six minutes, and 0.28 ± 0.06 inches/hr between six and nine minutes. The decline in infiltration rate over time represents an approach to steady state saturated infiltration. From the time the pits were established in November until infiltration rates were measured, the plots received 6.69 inches of precipitation (NOAA 2003). Thus, the pits were exposed to substantial slaking and sedimentation; processes that reduce infiltration effectiveness of channels created by chiseling (Wilkins et al. 1996, Schillinger and Wilkins 1997).



a b

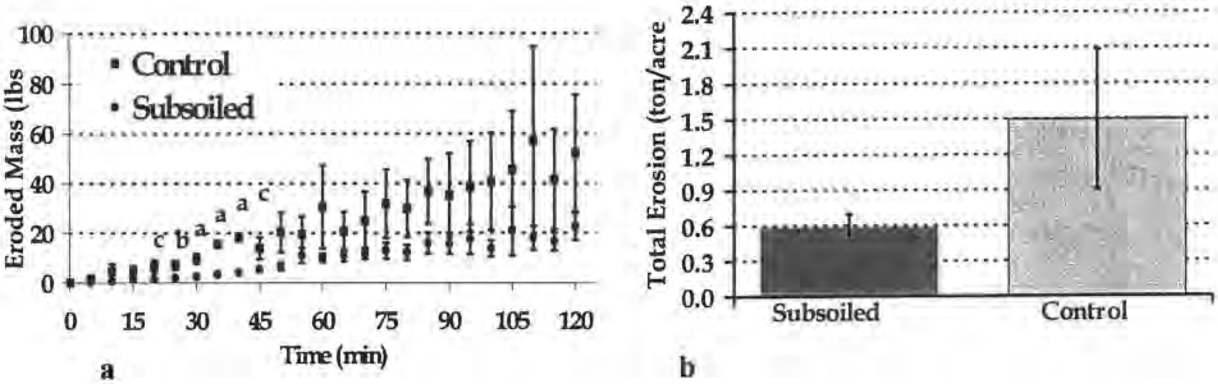
Figure 3. Runoff averages and standard errors (n = 4) from the first 2 hours of simulated rainfall on rotary-subsoiled and control treatments at Harrington: **a)** Runoff rates in cubic feet per second (cfs) from plots at 5-minute intervals following initiation of flow. Letters above incremental data points indicate significance of difference between treatments; **a:** P 0.01, **b:** P 0.05, and **c:** P 0.10; **b)** total runoff from 1.8 inches of simulated rainfall.

Water infiltration into frozen soil depends on soil texture and structure, tillage practices, quantity of residue on or mixed into soil, soil water content at the time of freezing, and the depth of freezing. Infiltration rate increases with increased rainfall intensity or under ponded conditions (Lusby and Lichty 1983). In soils chiseled after freezing, Pikul et al. (1996) recorded a ponded infiltration rate of about 0.83 inches/hr in soil frozen to a depth of 0.43 inches. This rate is nearly three times greater than measured (0.28 inches/hr) in soil frozen to a depth of 1.97-inches in our simulated rainfall study, after the soil had thawed in a random sample of pits. This finding suggests that continuous channels are more effective for reducing runoff than independent pits. However, when the depth of frozen soil extended down to 13.78 inches, infiltration rate for a continuous-channel treatment decreased to 0.04 inches/hr on 7.5 ft^2 plots (Pikul et al. 1996).

Subsoiling and erosion

Throughout the simulation event eroded soil mass was greater for the control plots than subsoiled plots. The eroded mass was significantly ($P < 0.01$) greater for the control treatment than for the subsoiled treatment from 20 to 45 minutes after runoff had begun (Fig. 4a). The greater variability in the control versus subsoiled treatments was caused by an exceptionally high erosion rate from one control plot. Despite the shallow depth of freezing, patches of frozen soil remained at the end of the simulations in both treatments. There were no obvious observed or measured differences in the plots used for both treatments other than the pits created by rotary subsoiling. We speculate that the pits detained enough sediment and created sufficiently more soil surface area so that the capacity to carry soil in the runoff was uniformly reduced.

Total eroded soil mass was 1.5 ton/acre from the control treatment compared to 0.58 ton/acre from the rotary-subsoiled (Fig. 4b). Working with continuous channels created by chiseling, Schillinger and Wilkins (1997) reported annual erosion of 1.1 ton/acre from the control treatment compared to no soil loss from the chiseled treatment, during a



a   b

Figure 4. Eroded mass averages and standard errors (n = 4) from simulated rainfall plots: **a)** pounds (lbs) from plots at 5-minute intervals following initiation of flow. Letters above incremental data points indicate significance of difference between treatments; **a: P** 0.01, **b: P** 0.05, and **c: P** 0.10; **b)** total eroded mass in tons per acre from 1.8 inches of simulated rainfall.

relatively dry winter. However, during a wet winter with four major precipitation events, soil loss was 7.0 ton/acre and 1.2 ton/acre in the control and subsoiled treatments, respectively.

Soil erosion resulted from interrill processes, predominately sheet wash, although micro-rills were beginning to form by the end of the simulations. Micro-rills formed where water had ponded in furrows or pits, and the water began escaping through cracks in the soil surface that had formed as a result of drying and freezing. Raindrop splash alone caused little erosion because of the small drop size ($D_{90} \leq 0.01$ inch) produced by the rainfall simulator (Bubenzer et al., 1985).

In our study, where rainfall was simulated at a rate equivalent to the total precipitation expected to fall in a 24-hr period once every 75 years (2.13 inches), the rotary-subsoiled treatment had 40 percent less erosion than the control treatment. This reduction in soil loss from rotary subsoiling is greater than the 13 percent reduction reported by Schillinger and Wilkins (1997) in the third rainstorm of 1.85 inches precipitation, which was preceded by two storms with an accumulated total precipitation of 6.29 inches. A direct comparison of results in the two studies is difficult, because of plot size, rainfall intensity, and erosion processes (i.e., inter-rill vs. rill).

Conclusion

Rotary subsoiling increased net over-winter soil water gain in 2 of 6 years. No measurable rill erosion occurred in either treatment in any year. There were no differences in winter wheat grain yield between the rotary subsoiling and control treatments in any year or when analyzed over the 6 years. Rotary subsoiling reduced runoff and soil loss during rainfall simulation onto frozen soil. Reduction in the eroded soil mass for the subsoiled treatment was statistically significant during the 20- to 45-minute period after runoff had begun.

Rotary subsoiling reduced runoff by 38 percent and improved infiltration compared to the control. The infiltration rate for the subsoiled treatment (0.26 inch/hr) was twice that for the control (0.13 inch /hr). Total quantity of eroded soils were 0.58 and 1.52 ton/acre for the rotary-subsoiled and control treatments, respectively. Rotary subsoiling will benefit over-winter soil water storage in some years and has potential to reduce runoff and soil loss during intense and short-duration rainstorms on residue-deficient farmland when soil is frozen or partially frozen. We conclude that rotary subsoiling is a low-cost practice that will benefit soil water storage in some years and will decrease potential soil loss on residue-deficient hill slopes during wet winters in the Pacific Northwest.

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SEED SIZING AS A TOOL FOR DRILL SETTINGS IN PRECISION AGRICULTURE

Sandy Macnab

Abstract

Wheat producers can select an economically and ecologically efficient seeding rate at planting by knowing the size of seed, in terms of number of seeds per pound. This helps ensure a plant stand best suited for the given production area, season, and variety. Wheat seed size is influenced by growing conditions of a given year, agronomic zone, and variety. Without the use of seed sizing to determine seeding rate, plant populations can be 30 percent over or under the desired carrying capacity.

Key words:
seed size, precision wheat seeding

Introduction

Cereal producers seeking to optimize planting efficiency and stand consistency should first determine the average kernel weight of the seed to be planted. Seeding rates can be adjusted using this information in order to achieve desired plant populations each year regardless of the year-to-year variations in seed-lot kernel density. Failure to adjust drill settings with every lot can cause plant stands to vary as much as 30 percent from the desired plant population.

Many factors influence seed weight, the inverse of which is reported in terms of kernels per pound. The lower the number of seeds per pound, the larger the seed size.

The number of seeds per pound can vary significantly by crop year as seen in Table 1. Kernels per pound of 'Stephens' wheat ranged from a high of 16,609 in 2003 to a low of 8,884 in 1998. Additionally, the number of seeds per pound can vary significantly by production location (Table 2) and by variety (Table 3) in a given year. For example, Table 2 reveals that across nine Oregon sites in 2001, the kernels per pound of the variety 'Stephens' varied by over 5,600 kernels. Table 3 demonstrates variations of kernel-per-pound-counts of seven commercial varieties at three locations in 2002, emphasizing the need to select planting rates based on a common measurement.

Table 1. 'Stephens' wheat kernel counts by year, Sherman County, Oregon.

Year	Kernels/lb
2003	16,609
2002	12,270
2001	14,836
2000	14,187
1999	11,445
1998	8,884
1997	9,155
1996	9,328
1988-1995	8,604 to 14,634

Table 2. 'Stephens' wheat seed counts by location (2001)

	Kernels/lb	% of average
Corvallis	9,144	82.3
LaGrande	9,256	83.3
Ontario	9,598	86.4
Pendleton	10,902	98.1
Kent	11,182	100.6
Madras	11,630	104.6
Hermiston	11,701	105.3
Wasco	11,780	106.0
Moro	14,822	133.4
Average	11,112	

Table 3. Kernels per pound by variety and Oregon location (2002).

Variety	Moro	Wasco	Pendleton
Edwin	16,214	16,815	17,328
Gene	15,337	12,160	15,286
Madsen	4,740	15,133	15,234
Rely	16,752	16,610	17,803
Rod	15,133	14,401	16,042
Stephens	12,270	11,690	13,969
Weatherford	13,633	14,413	16,042

With significant variation in seed size, producers can practice precision agricultural techniques by adjusting their seeding rates with each different lot of seed sown.

The seeding chart (Table 4) can be used by a producer to determine the proper seeding rate based on the desired plant population. The seeding rates are expressed in terms of "lbs/acre" based upon the kernel weight of the seed. Seeding rates provided in Table 4 were calculated with the assumption that 92 percent of the seeds planted would produce a viable seed.

Table 4. Seeding rate at various kernel weights to achieve desired plant populations[1].

Kernels/lb	**16 plants/ ft ^{2}**	**18 plants/ ft^2**	**20 plants/ ft ^{2}**	**22 plants/ ft^2**	**24 plants/ ft^2**
		Seeding rate (lb/ acre)			
8,500	89.1	100.0	111.4	122.5	133.7
9,000	84.2	94.7	105.2	115.7	126.3
9,500	79.7	89.7	99.7	109.6	119.6
10,000	75.7	85.2	94.7	104.2	113.6
10,500	72.1	81.2	90.2	99.2	108.2
11,000	68.9	77.5	86.1	94.7	103.3
11,500	65.9	74.1	82.3	90.6	98.8
12,000	63.1	71.0	78.9	86.8	94.7
12,500	60.0	68.2	75.8	83.3	90.9
13,000	58.3	65.6	72.8	80.2	87.4
13,500	56.1	63.1	70.1	77.2	84.2
14,000	54.1	60.8	67.6	74.4	81.2
14,500	52.2	58.8	65.3	71.8	78.4

[1]Assumes 92 percent of seeds will produce viable seedlings.

The seeding chart shows rates of 16, 18, 20, 22 and 24 plants/ft^2. Columbia Plateau research results suggest that soil depth and moisture combine to influence the desired seeding rate for a given area. A producer might select 16 plants /ft^2 in shallower soils or where other conditions may limit production potential; 18 is the "norm" for dryland, low rainfall deeper soils; 20 might be used in higher elevations with colder soils or when seeding later in the seeding window; 22 can be used in irrigated or higher precipitation areas; and 24 is optimal for spring seeded wheat. Growers may wish to conduct their own rate trials in their own conditions.

SEED TREATMENTS FOR CHICKPEA (GARBANZO BEAN)

Richard Smiley, Jennifer Gourlie, Ruth Whittaker, Sandra Easley, Karl Rhinhart, Erling Jacobsen, Abby Burnett, Jonathan Jackson, Deborah Kellogg, and Tina Zeckman

Abstract

Seed treatment fungicides were evaluated for their effect on productivity of a *kabuli* chickpea ('Sinaloa B') at Moro and Pendleton, Oregon, during 2002 and 2003. Seed treatments improved emergence and grain yield by reducing Pythium damping-off at the time of seedling emergence. Fungicide seed treatments did not reduce the incidence or severity of root diseases on mature plants. Treatments also failed to improve the market grade, compared to grain produced from untreated seed. This research confirmed the need to treat *kabuli* chickpea with fungicide seed treatments to maintain optimum productivity. The importance of fungicide mixtures capable of protecting against seed transmission of the Ascochyta blight pathogen was also discussed. A fungicide-by-disease matrix was provided as a guide for preparing mixtures of seed dressings.

Key words: chickpea, damping-off, *Pythium*, root diseases, seed treatment

Introduction

Chickpea is a crop of interest to growers in the Pacific Northwest. Acreage of chickpea has increased in response to a declining market demand for pea, to breeding efforts that have expanded the areas where chickpea varieties are adapted, and to an increasing amount of interest in annual cropping systems in regions with low rainfall. Little research had been performed on management of chickpea diseases in Oregon.

Chickpea, like other food legume crops, maybe affected by several soilborne fungal pathogens that infect and injure roots and lower stem tissue. Each pathogen may individually cause seed rot, seedling damping-off, or root rot. It is, however, common for two to five different pathogens to be identified on affected chickpea plants. The fungi generally act together to cause a root-rot complex rather than a single disease. Components of the complex may include the following pathogens and diseases: *Aphanomyces euteiches* (Aphanomyces root rot), *Fusarium solani* (black root rot), *Rhizoctonia solani* (wet root rot), *Pythium* species (Pythium damping-off and root rot), and *Thielaviopsis basicola* (black streak root rot). The complex may reduce emergence and root branching and elongation, and may cause light- to dark-colored lesions that may be dry or wet, and sunken or superficial, on the root surface. Economic damage is greatest when the root-disease complex is combined with drought, impediments to deep rooting, or other stress factors. Damage from the root-disease complex can be minimized but not controlled.

Chickpea can also be damaged by Fusarium wilt, caused by *Fusarium oxysporum*. This soilborne pathogenic fungus infects roots but is not considered a component of the root rot complex because the symptoms of foliar wilting occur in response to a plugging of the vascular (water transport) system in roots and stems, in contrast to a physical degradation of root tissue caused by the fungi involved in the root rot complex.

Kabuli chickpea is the relatively large-seeded type also known as "garbanzo bean". *Kabuli* chickpeas have a very thin seed coat lacking the phenolic compounds that resist infection by soil fungi. This makes them particularly susceptible to infection by soilborne pathogenic fungi. *Desi* chickpea has a smaller seed size and a thicker seed coat containing phenolic mold inhibitors, causing it to be more resistant to seedling infection. The root-disease complex is best managed by treating seed with a mixture of fungicides, by creating seedbed conditions that favor rapid seed germination and seedling emergence, and by planting *kabuli* and *desi* chickpeas at soil temperatures above 50°F and 45°F, respectively. Chickpea is most prone to damage when planted in soils with pH values below 6.5, in poorly drained sites, or in fields immediately following another pulse crop.

The objective of this study was to evaluate seed treatments to provide additional guidance to chickpea growers, suppliers, and advisory personnel. This paper describes the results of seed treatment trials at Moro and Pendleton during 2002 and 2003.

Methods

Seed treatments were evaluated on *kabuli* chickpea (*Cicer arietinum* cv 'Sinaloa B') at two stations of the Columbia Basin Agricultural Research Center. Mean annual rainfall (20-year mean) at Pendleton and Moro is 17.9 inches and 11.5 inches, respectively. Soils at each site are Walla Walla silt loams naturally infested with some or all of the pathogens.

During 2002, the trial at Moro was established in a field planted to spring barley during 2000 and maintained as unplanted, cultivated summer fallow for 19 months from harvest to planting. The 2003 trial at Moro was planted in a field where winter wheat was harvested during August 2001; cultivated summer fallow was maintained during 2002 and held through the second winter with minimal vegetation (i.e., a 20-month interval from harvest to planting).

During 2002, the trial at Pendleton was planted in a field cropped annually without tillage. Wheat was grown during 2000, and 'Sinaloa' chickpea was grown during 2001. A root-disease complex heavily damaged the chickpea crop during 2001, and the field was maintained as a chemical fallow through the winter of 2001-2002. These conditions created an unusually high potential for root diseases during 2002. The 2003 trial at Pendleton was planted in a field where no-till winter barley was harvested during July 2002. The field was maintained without cultivation through the winter (i.e., a 9-month interval from harvest to planting).

At Pendleton, during 2002, Roundup® herbicide was applied to kill weeds on February 14, and Pursuit® herbicide was applied to soil on March 26. At Moro, Prowl® herbicide was applied to soil on April 8. Chickpea seed was planted in moist soil on April 8 at both locations. 'Type-N' *Rhizobium* inoculant was dusted over treated seed in seed packets one day before planting. At Moro, seed was planted at 2-inch depth with a seed-zone temperature of 56°F. At Pendleton, seed was planted at 1-inch depth with a seed-zone temperature of 49°F. Seed at both locations was planted at six seeds/ft^2 into 5- by 20-ft plots with a Hege double-disk drill equipped with a cone seeder and nine openers spaced at 6 inches.

During 2003, Pursuit herbicide was applied to soil on March 11 at Pendleton and April 10 at Moro. *Rhizobium* inoculant was dusted over treated seed in seed packets about 1 hour before planting. Seed was planted on April 9 and 10 at 1-inch depth into moist soil. Seed-zone temperature was 48°F at Moro and 50°F at Pendleton. Seed at both locations was planted at three seeds/ft^2 into 5- by 40-ft plots with a John Deere HZ drill equipped with a cone seeder and four openers spaced at 14 inches. For all except one treatment (Tables 1 and 2), starter fertilizer (16-20-0, at 10 lb N/acre) was banded 1 inch below the seed.

All experimental designs were randomized complete blocks with treatments replicated four times during 2002 and seven times during 2003. Data included stand density 1 month after planting, disease incidence and severity during July, and grain yield in August. Grain market grades were determined during 2003 by using standard sieve-size grading procedures. Data were evaluated by analysis of variance and, when variables differed at $P < 0.10$, means were separated by the least significant difference test.

Results

Growth and yield were limited by drought conditions at both sites during each year of testing. "Growing-season" precipitation (Sep-Aug) deviated from the 20-year mean by –27 percent at Pendleton and –26 percent at Moro during 2002, and by –10 percent at Pendleton and –17 percent at Moro during 2003. Spring-season precipitation (Mar-May) during 2002 deviated from the 20-year mean by –32 percent at Pendleton and –35 percent at Moro during 2002, and by –58 percent at Pendleton and –41 percent at Moro during 2003. There was no rain during July and August 2003.

Plants from untreated controls and randomly selected plots were examined to determine if differences occurred in overall plant health during 2002. Because no differences were detected, systematic sampling was not performed. Roots and cotyledons in the wheat-fallow-chickpea rotation at Moro had considerable cortical root rot, characteristic of black root rot and wet root rot, but no vascular browning characteristic of Fusarium wilt (*Fusarium oxysporum*). At Pendleton, each of the diseases and parasites was present in the no-till annual recrop system. Extensive lesions on both cotyledons and roots were present on nearly all plants and up to 5 percent of plants died from wilt during the seedling stage.

Plant stands and yield did not differ significantly ($P < 0.10$) among treatments at either location during 2002 (Table 1). Yields were higher than the untreated control for all treatments at each location, indicating potential economic benefits from all treatments. This potential benefit from seed treatment was considered to be a response to differences in early establishment rather than a suppression of root and cotyledon diseases on mature plants. However, the number of replicates for each treatment in 2002 was probably too low to allow these differences to be statistically separated with confidence.

The number of replicates for each treatment was increased during 2003 in an effort to increase the sensitivity of the statistical analysis. Stand density differed significantly among treatments at both locations (Table 2). All treatments except GB34 (a bacterial seed treatment) had higher stand density

Table 1. Chickpea seedling emergence (28 days after planting) and seed yield, as affected by seed treatments at Moro and Pendleton, Oregon, during 2002.

Seed treatment	Rate/cwt	Plants/ft of row 28 days after planting		Yield (lb/acre)	
		Moro	Pendleton	Moro	Pendleton
Control	water only	1.3	2.4	817	584
Captan 400 + Allegiance………………….	2.5 fl oz + 0.75 fl oz	1.8	2.5	1003	625
Captan 400 + Allegiance + Kodiak Conc….	2.5 fl oz + 0.75 fl oz + 0.125 oz	2.4	2.1	909	654
Captan 400 + Allegiance + LSP…………..	2.5 fl oz + 0.75 fl oz + 3.3 fl oz	1.7	2.5	933	681
Captan 400 + Allegiance + L1115-A………	2.5 fl oz + 0.75 fl oz + 0.16 oz	2.2	2.4	976	696
Captan 400 + Allegiance + L1028-C………	2.5 fl oz + 0.75 fl oz + 0.08 fl oz	2.0	3.2	948	671
Apron XL + Maxim 4FS + WE SD4648'….	0.16 fl oz + 0.08 fl oz + 1.6 fl oz	2.1	2.8	957	679
Apron XL + Maxim 4FS + WE SP4648'…..	0.08 fl oz + 0.4 fl oz + 1.6 fl oz	1.9	2.1	918	615
Apron XL + Maxim 4FS …………………..	0.08 fl oz + 0.4 fl oz	1.8	2.3	985	607
Apron XL + Maxim 4FS…………………..	0.08 fl oz + 0.3 fl oz	2.0	2.2	996	664
mean		1.9	2.4	944	647
lsd $_{0.10}$		ns	ns	ns	ns
P		0.10	0.28	0.12	0.78
CV (%)		22	29	9	15

Table 2. Chickpea seedling emergence, yield and market quality, as affected by seed treatments at Moro and Pendleton, Oregon, during 2003.

		Plants/ft of row 31 days after planting		Yield (lb/acre)		Grades A + B (% of total yield)	
Seed treatment [1]	Rate/cwt	Moro	Pendleton	Moro	Pendleton	Moro	Pendleton
Control	water only	0.5	1.6	318	512	93.5	97.5
GB34	0.10 oz	0.7	1.6	347	533	94.8	96.9
Captan 400 + Allegiance	2.5 fl oz + 0.75 fl oz	3.3	2.5	407	721	95.4	97.9
Captan 400 + Allegiance (no starter fertilizer)	2.5 fl oz + 0.75 fl oz	3.4	2.8	404	665	88.1	97.3
Captan 400 + Allegiance + LSP	2.5 fl oz + 0.75 fl oz + 3.4 fl oz	4.3	2.5	414	607	95.6	96.5
Captan 400 + Allegiance + GB34	2.5 fl oz + 0.75 fl oz + 0.10 oz	3.2	3.3	463	815	95.3	97.3
Captan 400 + Thiram 42-S + Allegiance	1.8 fl oz + 2.5 fl oz + 0.72 fl oz	2.4	3.0	423	736	93.4	97.2
RTU Vitavax-Thiram 42-S + Allegiance + Kodiak	6.8 fl oz + 0.75 fl oz + 0.13 oz	3.6	2.9	434	718	95.4	97.3
Topsin 2.8 + Allegiance + L1226-A1	0.46 fl oz + 0.75 fl oz + 0.32 oz	3.1	3.0	450	777	95.5	97.8
Apron XL + Maxim 4FS	0.32 fl oz + 0.08 fl oz	2.9	2.9	430	789	93.2	96.9
Apron XL + Maxim 4FS	0.32 fl oz + 0.16 fl oz	3.8	3.2	430	744	94.6	97.3
Apron XL + Maxim 4FS	0.32 fl oz + 0.32 fl oz	3.8	3.1	422	761	95.1	97.3
Apron XL + Maxim 4FS + Protégé	0.32 fl oz + 0.08 fl oz + 0.15 fl oz	2.8	3.3	466	728	95.1	97.4
Apron XL + Maxim 4FS + Protégé	0.32 fl oz + 0.08 fl oz + 0.38 fl oz	2.2	3.1	421	726	99.2	96.2
Apron XL + Mertect 340-F	0.11 fl oz + 2.14 fl oz	3.2	2.8	467	797	95.6	97.7
mean		2.9	2.8	420	709	94.7	97.2
$lsd_{0.05}$		1.0	1.1	69	128	3.5	ns
P > F		<0.001	0.03	0.002	<0.001	<0.001	0.93
CV (%)		31.8	36.5	15.4	16.9	3.5	1.7

[1] All except one treatment, as noted, included starter fertilizer (16-20-0) placed below the seed.

than the untreated control, indicating the value of a fungicide capable of suppressing damping-off when planting into cool, moist soil. Diseases were evaluated on plants from four treatments: untreated control, Apron® + Maxim® + Protégé®, Captan® + Allegiance®, and Captan + Allegiance + LSP. At Moro, blackening of cotyledons was more severe ($P = 0.07$) in the untreated control compared to the three fungicide treatments, but the incidence did not differ ($P = 0.28$) among treatments. Root rot severity did not differ ($P = 0.31$) among treatments, but the incidence of the root rot complex was higher ($P = 0.002$) in the three fungicide treatments (96 to 97 percent) than in the untreated control (79 percent). At Pendleton, blackening of cotyledons was more severe ($P = 0.01$) and was present on a higher percentages of plants ($P = 0.07$) in the untreated control compared to the three fungicide treatments. Root rot severity and incidence did not differ significantly among treatments. There was no vascular browning, characteristic of Fusarium wilt, at Pendleton during 2003, and the incidence of wilt at Moro was very low (none to 1 percent). Yields at both locations were lower in the untreated control and GB34 treatment compared to other treatments (Table 2). Relative relationships for yields and market grades for each treatment are illustrated in Figure 1.

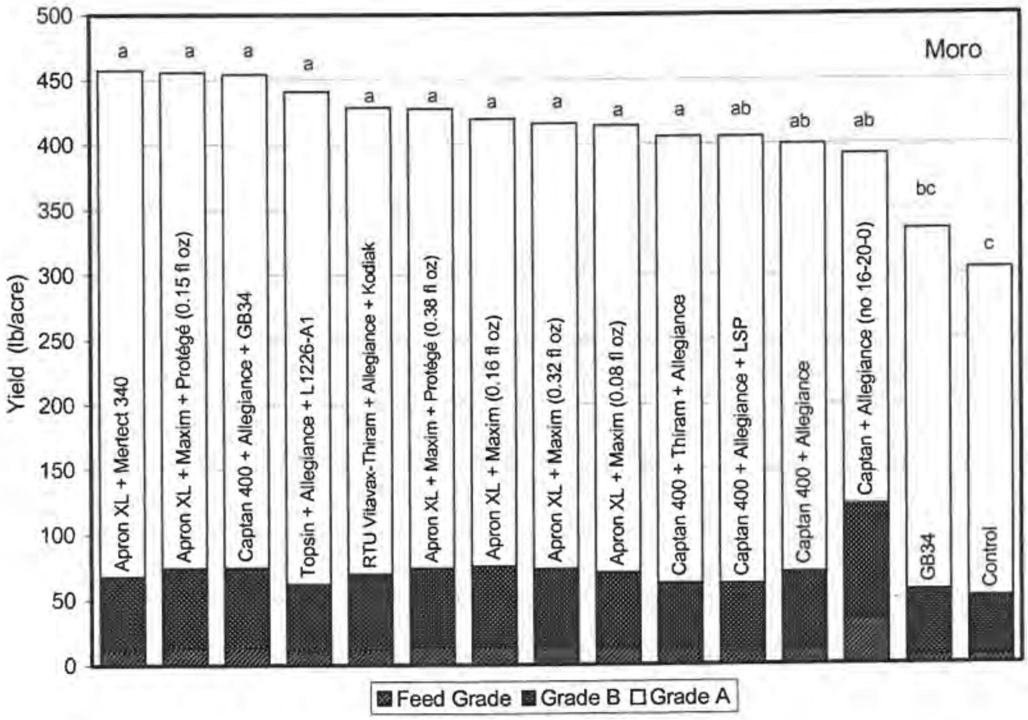
The effect of starter fertilizer banded below the seed was evaluated for the Captan + Allegiance treatment. The starter fertilizer did not improve yield at either location (Table 2 and Fig. 1). However, the fertilizer did improve chickpea quality at Moro, as assessed by percentages of peas in Grades A + B.

Discussion

It was clear that *kabuli* chickpea seeds must be treated with a fungicide before planting, particularly when planting into cool soil. Seedling emergence and grain yield were improved each year, although the differences between treated and untreated seed were not statistically significant during 2002. The fungicides suppressed damping-off by species of *Pythium*, but had little or no impact on severity or incidence of the root-rot complex that occurs on mature plants. It was clear that chickpea productivity was enhanced by application of either mefenoxam or metalaxyl fungicide, each of which was effective in suppressing Pythium damping-off. Mefenoxam- and metalaxyl-based fungicides are more effective than captan-based fungicides for controlling seed rots and seedling diseases, and also have less potential than captan for reducing nodulation.

The use of multiple management strategies is important for minimizing damage from seedling damping-off and root rot. The impact of these diseases can be kept to a minimum by treating seeds with a mixture of protective fungicides, using long rotations in which chickpea crops are separated by 4 or 5 years, avoiding planting chickpea immediately after another pulse crop, avoiding planting chickpea in fields that are poorly drained or are acidic ($pH < 6.5$), planting *kabuli* chickpea into warmer soil than for *desi* chickpea (>50°F or 45°F, respectively), assuring good fertility for seedling establishment, and by avoiding the mixing of fertilizer with the seed in the drill box, which is known to reduce emergence due to salt toxicity.

Some fungicides can reduce the efficiency of *Rhizobium* inoculant. Granular forms of inoculant are usually less affected by fungicide treatment than liquid or peat formulations. It is suggested that the rate of inoculum be increased on fungicide-treated seed to compensate for the toxicity of certain fungicides to *Rhizobium* bacteria.



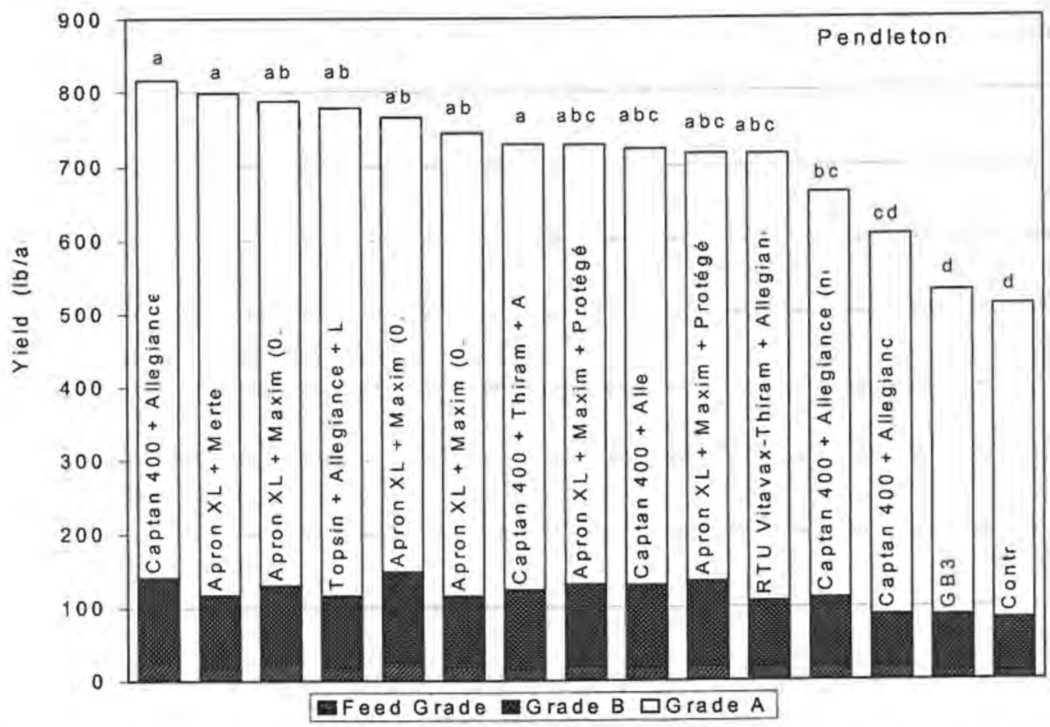


Figure 1. Total yield and portions of yield in three market grades for 'Sinaloa B' chickpea produced with 14 seed treatments or no treatment at Moro and Pendleton, Oregon, during 2003. Yield bars having the same letter at the top of the bar do not differ significantly ($P < 0.05$) from another yield bar with the same letter.

Table 3. Seed treatment fungicides for suppressing diseases of chickpea.

Fungicide active ingredient [1]	Trade name(s)	Ascochyta blight	Seed rot and seedling damping-off complex			
			Pythium component		Other components [2]	
			Seed rot; damping-off	Root rot	Seed rot	Damping-off; seedling blight
captan	Captan		x [3]		x	x
fludioxonil	Maxim				X	X
mefenoxam	Apron		X	X		
metalaxyl	Allegiance		X	X		
thiabendazole	TBZ; LSP	X [4]				

[1]Maximum protection can be achieved by mixing two or three fungicides to control diseases in each of the five columns in the table.
[2]Currently, there are no effective chemical controls for the root-disease complex on older seedlings and mature plants, including all components of Aphanomyces root rot.
[3]Control is anticipated to be stronger from products designated by "X" compared to products designated by "x".
[4]For preventing transmission of the pathogen on the seed; will not protect against post-emergent infections.

While it is important to suppress damping-off to establish a uniform and full stand, it is also important that growers apply a thiabendazole fungicide to prevent potential losses from Ascochyta blight (*Ascochyta rabiei*, also known as *Didymella rabiei* or *Phoma rabiei*). Ascochyta blight is the foliar disease that has the greatest potential to destroy chickpea crops. The pathogen is spread on seed and by rain splash, wind, infested residue, and volunteer plants. Ascochyta blight can be controlled by a combination of genetic resistance and crop husbandry. Control measures include planting certified, disease-free seed of resistant varieties, planting chickpea only once in 3 to 5 years on the same field, treating seed with a fungicide such as thiabendazole (Table 3, modified from Corp et al. 2004), monitoring the crop and, if necessary, applying a foliar fungicide such as pyraclostrobin (Headline®) or chlorothalonil (Bravo®). If a crop shows symptoms of Ascochyta blight, it is very important to destroy all infested residue after harvest and to kill all volunteer plants. Infested residue can allow spores of the pathogen to be released for up to 3 years. Inversion tillage that buries all residue is also effective for breaking the disease cycle.

References

Corp, M., S. Machado, D. Ball, R. Smiley, S. Petrie, M. Siemens, and S. Guy. 2004. Chickpea Production Guide. Oregon State Univ. Ext. Publ. EM 8791-E. 14 pages. Published on-line at http://eesc.orst.edu/agcomwebfile/EdMat/em8791-E.pdf

PRECIPITATION SUMMARY - PENDLETON

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

Crop Yr.	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total
74 Year Average	**.73**	**1.38**	**2.08**	**2.05**	**1.96**	**1.54**	**1.73**	**1.52**	**1.47**	**1.21**	**.34**	**.47**	**16.48**
1983-84	.82	.91	2.79	3.44	.99	2.56	3.23	2.37	2.11	2.05	.05	1.25	22.57
1984-85	.98	1.18	3.43	1.96	.69	1.49	1.33	.65	.89	1.42	.05	.98	15.05
1985-86	1.54	1.34	2.66	1.27	2.38	3.04	1.94	.83	1.79	.09	.61	.19	17.68
1986-87	1.87	.91	3.41	.95	2.08	1.31	1.85	.83	1.63	.62	.47	.06	15.99
1987-88	.04	0	1.44	1.61	2.60	.32	1.65	2.59	1.79	.94	0	0	12.98
1988-89	.40	.08	3.65	1.10	2.86	1.55	2.95	1.94	2.19	.33	.15	1.19	18.39
1989-90	.24	1.00	1.65	.49	1.43	.63	1.89	1.77	2.14	.70	.37	.76	13.07
1990-91	0	1.37	1.73	1.18	1.15	.86	1.71	1.01	4.73	2.22	.15	.24	16.35
1991-92	.03	.89	4.18	.97	.96	1.34	.85	1.29	.20	.90	1.74	.78	14.13
1992-93	.58	1.70	2.61	1.30	2.43	1.04	2.32	2.67	1.58	2.01	.47	2.60	21.31
1993-94	0	.30	.49	1.91	2.38	1.67	.52	1.18	2.88	.75	.33	.07	12.48
1994-95	.76	1.44	3.77	1.83	2.75	1.15	2.35	2.92	1.56	1.73	.22	.41	20.89
1995-96	.93	1.35	2.95	2.37	2.79	2.45	1.49	2.33	2.00	0.39	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	0.40	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	0.36	1.91	1.88	1.02	1.36	1.33	1.41	1.12	1.02	1.39	0.23	0	13.03
2002-03	0.24	0.61	1.09	3.06	3.25	2.18	2.20	1.78	1.01	0	0	0.23	15.65
2003-04	0.70	0.68	1.68	3.33	2.77	2.29	.85						
20 Year Average	**.67**	**1.22**	**2.54**	**1.79**	**2.03**	**1.59**	**1.91**	**1.64**	**1.77**	**1.03**	**.31**	**.51**	**17.00**

PRECIPITATION SUMMARY - MORO

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

Crop Yr.	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total
94 Year Average	**.57**	**.92**	**1.69**	**1.63**	**1.62**	**1.17**	**.97**	**.79**	**.82**	**.67**	**.22**	**.28**	**11.35**
1983-84	.52	.62	2.45	2.31	.17	1.07	2.34	1.32	.97	1.09	.17	0	13.03
1984-85	.53	.86	3.18	.41	.27	.97	.44	.14	.63	.92	.05	.14	8.54
1985-86	1.11	1.09	1.19	1.12	1.84	2.39	.98	.34	.35	.06	.54	.07	11.08
1986-87	1.52	.45	1.53	.78	1.68	1.10	1.54	.28	.99	.29	.78	.11	11.05
1987-88	.07	.01	.66	3.23	1.60	.21	1.25	2.21	.55	1.02	.04	0	10.85
1988-89	.56	.02	2.51	.22	1.33	.77	1.91	.84	.91	.08	.11	.50	9.76
1989-90	.07	.59	.96	.48	1.91	.17	.76	.79	1.36	.39	.15	1.43	9.06
1990-91	.29	1.27	.61	.74	.87	.60	1.43	.40	.77	1.27	.33	.16	8.74
1991-92	0	1.40	2.57	1.02	.47	1.64	.64	2.38	.04	.28	.81	.02	11.27
1992-93	.68	.85	1.50	1.68	1.42	1.47	1.68	1.22	1.42	.87	.39	.30	13.48
1993-94	.02	.09	.41	.68	1.40	.90	.55	.40	.62	.61	.11	.07	5.86
1994-95	.19	2.27	1.79	.90	3.67	1.18	1.14	1.95	.97	1.45	1.10	.17	16.78
1995-96	1.02	.64	3.20	2.20	1.86	2.43	.65	1.57	1.44	.36	.15	.03	15.55
1996-97	.55	1.56	2.63	4.18	1.57	.84	1.28	1.26	.55	.56	.13	.57	15.68
1997-98	.46	1.61	.66	.29	2.49	1.30	1.02	.66	3.15	.26	.26	.06	12.22
1998-99	.38	.16	2.57	1.34	1.34	1.00	.51	.06	.56	.11	.09	.23	8.35
1999-00	0	.83	1.62	.62	1.77	2.43	.76	.44	.48	.20	0	0	9.15
2000-01	.30	1.39	.60	.35	.43	.53	.81	.71	.34	.50	.02	.23	6.21
2001-02	.53	1.03	2.02	1.17	.68	.65	.42	.38	.66	.85	.04	0	8.43
2002-03	.02	.27	.59	2.65	1.92	1.26	.90	1.00	0.21	0	0	0.47	9.29
2003-04	0.25	0.65	.73	2.44	1.58	1.47	.61						
20 Year Average	**.44**	**.85**	**1.66**	**1.32**	**1.43**	**1.15**	**1.05**	**.92**	**.85**	**.56**	**.26**	**.23**	**10.72**

AVERAGE MAXIMUM TEMPERATURE SUMMARY - PENDLETON

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

Crop Yr.	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	MAX
74 Year Average	**78**	**65**	**49**	**42**	**40**	**46**	**54**	**62**	**71**	**79**	**89**	**88**	**115**
1983-84	73	65	53	30	42	47	55	58	65	73	90	88	102
1984-85	75	62	50	37	30	43	53	66	72	80	95	83	105
1985-86	70	62	35	26	43	46	59	61	69	85	83	93	104
1986-87	72	68	49	37	38	47	56	68	74	82	85	87	104
1987-88	83	72	52	41	40	50	56	64	69	77	90	88	102
1988-89	79	74	52	41	45	33	52	64	69	81	88	83	101
1989-90	80	65	54	40	44	46	57	68	68	78	92	87	108
1990-91	85	64	55	35	40	55	52	62	66	73	89	91	100
1991-92	82	67	48	43	44	51	59	65	76	86	86	89	104
1992-93	76	67	46	40	33	36	50	61	74	76	79	83	98
1993-94	81	68	46	41	49	42	58	65	72	78	92	88	107
1994-95	82	63	46	43	41	52	55	60	70	75	88	84	98
1995-96	81	63	54	40	43	42	52	63	65	78	92	89	107
1996-97	75	64	48	44	41	45	55	60	74	77	86	90	102
1997-98	79	65	50	41	47	53	55	61	67	78	95	92	111
1998-99	83	66	53	44	50	51	55	61	68	78	88	89	103
1999-00	80	66	56	45	42	47	53	67	70	78	88	89	105
2000-01	75	63	44	38	39	44	58	60	75	77	87	91	102
2001-02	83	65	52	44	46	51	49	62	69	81	93	86	110
2002-03	80	64	52	45	46	49	58	61	70	84	94	90	107
2003-04	83	71	49	44	34	48	61						
20 Year Average	**79**	**66**	**50**	**40**	**42**	**46**	**55**	**63**	**70**	**79**	**89**	**88**	**111**

AVERAGE MINIMUM TEMPERATURE SUMMARY - PENDLETON

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

Crop Yr.	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	MIN
74 Year Average	**43**	**35**	**31**	**27**	**24**	**29**	**32**	**36**	**42**	**47**	**51**	**50**	**-30**
1983-84	42	35	37	14	25	31	36	37	42	46	51	52	-26
1984-85	43	34	33	22	21	21	31	38	42	47	54	49	-16
1985-86	40	35	17	13	28	31	38	35	43	50	49	53	-21
1986-87	42	34	35	27	21	31	35	38	44	47	52	47	-3
1987-88	43	29	32	25	24	26	31	39	42	48	51	47	3
1988-89	42	39	35	27	28	15	33	39	42	48	49	52	-18
1989-90	41	35	34	26	31	26	31	38	42	49	54	53	-4
1990-91	45	36	35	14	23	34	31	36	42	46	51	53	-26
1991-92	42	33	34	30	33	34	32	39	41	51	53	52	11
1992-93	43	37	34	24	16	21	31	38	47	49	51	50	-12
1993-94	42	37	19	30	32	26	32	40	45	47	53	51	-4
1994-95	44	34	32	28	28	31	32	36	42	47	54	47	-5
1995-96	47	36	36	29	27	22	33	38	41	45	53	51	-21
1996-97	42	37	31	28	24	30	35	36	44	48	51	53	-3
1997-98	47	35	34	28	29	33	33	35	43	48	57	52	3
1998-99	49	33	36	26	32	32	33	32	39	47	49	54	-5
1999-00	38	32	36	32	29	32	31	37	44	46	51	48	19
2000-01	45	37	27	27	28	27	32	36	42	47	52	52	16
2001-02	45	34	34	28	28	29	30	34	40	50	54	48	18
2002-03	42	29	30	32	34	29	37	37	43	47	53	51	9
2003-04	46	40	26	29	21	30	34						
20 Year Average	**43**	**35**	**32**	**26**	**27**	**28**	**33**	**37**	**42**	**48**	**52**	**51**	**-26**

AVERAGE MAXIMUM TEMPERATURE SUMMARY - MORO

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

Crop Yr.	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	MAX
75 Year Average	**75**	**62**	**47**	**39**	**37**	**43**	**51**	**59**	**67**	**74**	**83**	**82**	**111**
1983-84	68	61	48	28	40	44	52	53	62			82	98
1984-85	70	57	45	35	29	40	50	61	67	75	89	78	99
1985-86	66	59	33	24	39	43	55	56	67	80	75	87	101
1986-87	67	65	48	34	36	44	51	63	70	78	78	82	98
1987-88	78	68	49	36	35	47	52	59	63	70	83	81	100
1988-89	74	71	49	39	44	32	48	62	66	76	78	77	99
1989-90	76	61	51	40	43	45	54	63	64	73	87	82	106
1990-91	80	60	52	34	39	51	49	58	62	68	83	86	98
1991-92	78	64	46	40	43	48	57	61	72	81	82	84	103
1992-93	71	62	46	37	30	35	47	57	71	71	73	80	95
1993-94	78	66	45	38	48	41	57	62	69	73	88	82	106
1994-95	80	62	45	42	37	49	52	57	68	71	81	78	96
1995-96	78	61	53	38	42	40	50	59	61	73	88	84	103
1996-97	72	61	47	42	40	45	53	57	71	73	80	85	99
1997-98	76	61	49	41	42	47	52	58	63	73	88	85	106
1998-99	81	62	50	41	47	48	52	57	64	71	81	83	100
1999-00	76	62	51	42	37	42	51	62	64	74	80	81	97
2000-01	72	60	41	36	36	42	54	57	71	72	81	85	100
2001-02	78	61	49	40	42	47	48	58	65	76	84	81	104
2002-03	76	61	49	40	43	47	56	57	66	78	88	84	102
2003-04	78	67	44	38	33	43	57						
20 Year Average	**75**	**62**	**47**	**37**	**40**	**44**	**52**	**59**	**66**	**74**	**82**	**82**	**106**

AVERAGE MINIMUM TEMPERATURE SUMMARY - MORO

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

Crop Yr.	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	MIN
75 Year Average	**46**	**38**	**31**	**26**	**24**	**28**	**32**	**36**	**42**	**48**	**54**	**53**	**-24**
1983-84	43	36	35	17	25	31	35	36	40			53	-13
1984-85	44	34	31	22	21	22	30	38	42	48	58	50	-7
1985-86	41	36	19	13	26	29	37	35	45	52	51	57	-15
1986-87	44	39	34	25	23	31	34	40	46	50	54	52	7
1987-88	49	38	32	25	25	29	33	39	41	48	52	50	4
1988-89	45	42	34	27	29	16	31	38	43	49	53	53	-15
1989-90	46	37	34	26	31	26	32	39	41	48	56	55	13
1990-91	49	37	35	17	22	33	30	36	41	46	54	56	-16
1991-92	47	37	33	30	31	35	35	40	45	53	55	54	12
1992-93	45	39	33	22	17	20	31	36	46	49	50	51	-3
1993-94	46	40	22	28	32	25	33	39	45	48	56	54	-3
1994-95	48	36	30	28	25	32	31	36	45	49	55	50	-2
1995-96	49	38	36	28	27	23	32	37	40	47	55	52	-15
1996-97	44	38	31	27	26	29	34	36	45	48	53	56	7
1997-98	49	38	33	28	27	32	33	36	43	48	57	54	2
1998-99	50	34	35	25	30	30	30	34	39	47	51	56	-2
1999-00	44	35	35	30	25	29	33	38	42	46	52	52	13
2000-01	52	38	27	25	26	26	32	35	43	47	54	56	10
2001-02	49	36	33	29	29	28	29	35	41	51	55	51	3
2002-03	45	33	27	33	33	29	35	35	42	50	57	56	7
2003-04	49	42	27	28	22	29	36						
20 Year Average	**46**	**37**	**31**	**25**	**27**	**28**	**33**	**37**	**43**	**49**	**54**	**53**	**-16**