Special Report 1047
June 2003

2003 Columbia Basin Agricultural Research Center Annual Report

In cooperation with
USDA • Agricultural Research Service

OREGON STATE UNIVERSITY
AGRICULTURAL EXPERIMENT STATION

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Agricultural Experiment Station
Oregon State University
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Columbia Plateau Conservation Research Center
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Editorial Committee
Steven Petrie, Chair
Patricia Frank, Copy Editor

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Sandy Frost
Steve Machado
Scott Oviatt
Mark Siemens
Katherine Skirvin
Richard Smiley

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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 bulletin contains a representative sample of the work in progress at these centers. A collection of bulletins over a three-year period will give a more complete assessment of the productivity and applicability of research and education. Changes in staffing, programming, and facilities at these centers during the past year are summarized below.

Promotions and Awards

Within the ARS staff, Amy Baker, Katherine Skirvin, and Stewart Wuest received promotions in 2002. Scott Oviatt was selected for the position of Physical Scientist (Category 3). All employees of the Columbia Plateau Conservation Research Center received the 2002 Pacific West Area Equal Employment Opportunity Award for their outstanding contributions in EEO/Civil Rights and student outreach. Amy Baker, Daryl Haasch and Chris Roager received awards for their contributions to the Center's safety program. Pat Frank, Tami Johlke, Dave Robertson, and Katherine Skirvin received performance awards, and a Certificate of Appreciation was presented to Richard Greenwalt. Certificates of Appreciation were also presented to the Harrington Project crew, Amy Baker, Bob Correa, Brian Currin, Hero Gollany, Daryl Haasch, Don Hulick, Dave Robertson, Katherine Skirvin, Dale Wilkins, John Williams, and Stewart Wuest. Pat Frank was appointed to the Pacific West Area Office Support Advisory Council.

Staff Changes

There were no staff changes within the OSU team of scientists, Extension Specialists and support personnel in 2002. Summer workers included Nathan Adelman, Heath Anderson, Kyle Bichler, Cathy Brown, Abby Burnett, Rachel Chambers, Joel Currin, Shannon Duff, Erin Elliott, Jeremy Gregory, Shaun Hacquet, Kurt Hendrix, Robert Humphreys, Jessica Justus, Dustin Larson, Sara Larson, Lenden Mabe, David Macnab, Scott Montgomery, Nicholas Sirovatka, David Sisson, Anna Smith, Amy Spratling, David Tanner, Deborah Thompson, Rebecca Tidwell, Alan Wernsing, and Ryan Wuest

There were several additions and changes in ARS staff during the past year (2002-2003). Dr. Dale Wilkins, Research Leader and Agricultural Engineer, retired February 28, 2003 after nearly 42 years of service. Stephan Albrecht, ARS Microbiologist, was appointed Acting Research Leader. Don Hulick was selected to fill the Agricultural Engineering Technician position. Marty Platt, who worked as a Computer Aid, resigned when he moved to Boise, ID. Gretchen Deutschlander was selected for a Summer Intern position in the erosion program. Other temporary employees included Stephanie Boyle, Brian Currin, Karin Dallas, Melissa Johnson, Jennifer Levy, Aurora Martin, Angela Sallee, Robert Sanchez, Christina Skirvin, Sam Womack and Byron Wysocki. Dave Hollenback worked six months in the agricultural engineering program. Lori Spencer, a Master of Science degree student in the Department of Environmental Science and Regional Planning at Washington State University, Tri-Cities campus, continued work with John Williams.

New Projects

OSU scientists and Extension Specialists rely on outside support for many of the research project they conduct. In 2002, OSU faculty members received a total of $541,000 from a variety of outside sources.

Stephen Machado, the OSU Dryland Cropping Systems Agronomist, has initiated an active field and greenhouse research program. The key points of his program are listed below.

- Long Term Experiments - He and Steve Petrie have initiated a new Long Term Experiment at the Sherman Station. The site selection and characterization (grid soil sampling for chemical and physical analysis, depth to clay pan determination) has been completed and the site has been solid seeded to spring wheat to homogenize the site. Treatments will be imposed on the site beginning in the fall of 2003.
- Alternative crops - Dr. Machado is screening native crops and crops from regions with climatic conditions similar to eastern Oregon to determine potential alternative rotational crops for this region. The crops being screened include cereals, legumes, brassica, grasses, and crops with industrial and pharmaceutical uses.
- Fusarium Root Rot and Soil Moisture Interactions - these experiments aim to determine if susceptibility of the plants to the disease is related to drought tolerance and to develop tillage and fertilizer treatments that conserve soil water to reduce drought stress during the final phases of plant growth.
- Chickpea agronomy – these experiments focus on screening for adaptable varieties and determining the best agronomic practices.
- Drought studies – this work aims at screening diverse wheat genotypes for drought stress traits including the "stay-green character" (the ability of leaves to remain green and photosynthetically active).

Richard Smiley traveled to France, Lebanon, Syria and Turkey on grant funds from the USDA-ARS to inspect equipment and learn new research techniques used to identify nematodes that affect wheat crops in Oregon. He has already begun to incorporate these new techniques in his field trials evaluating varieties for resistance to nematodes. Dr. Smiley will also be incorporating DNA-based procedures to improve the speed and reliability for identifying species of nematodes. In addition, Dr. Smiley will be incorporating new techniques of screening for resistance to Fusarium in his research program. He will be using techniques that permit him to evaluate thousands of lines instead of a few hundred using the current technology. Finally, he has established formal research agreements with scientists at these research centers; he will test the most promising germplasm for resistance to local strains of the pathogens.

Within ARS, John Williams is the lead scientist developing a new CRIS project for the Integrated Agricultural Systems National Program. The project, entitled "Cropping Systems and Land Management in Dryland Pacific Northwest," involves all ARS scientists, most principally Hero Gollany and

Mark Siemens. The objective of this project is to improve the economic and biological sustainability of conservation systems for winter wheat production in the semiarid Pacific Northwest.

An experiment was initiated to investigate the effects of different sources of organic carbon on both soil carbon sequestration and selected edaphic factors. This research is a collaborative effort of Stewart Wuest, Hero Gollany, and Steve Albrecht, with technical support from Amy Baker, Roger Goller, Tami Johlke, and Katherine Skirvin. The experiment is also being conducted in Sydney, MT; Lincoln, NE; and Prosser, WA.

A project to reduce erosion and increase water storage was carried out this winter near Harrington, WA, to investigate the effectiveness of rotary subsoiling over winter wheat in the fall. Eleven ARS employees from Pendleton managed rainfall simulation on frozen soil with the help of numerous volunteers from the Lincoln County Soil and Water Conservation District; Hanxue Qiu, Bruce Sauer, Bill Schillinger, and Harry Shafer, of Washington State University; Don McCool of ARS, Pullman; Amund Melville, Brad Murison and Cal Gilmer from Sprague Grange; and Jim Els of Harrington.

Facilities and Equipment

New storage buildings were erected at both the Pendleton and Sherman stations. The Sherman Endowment Fund generously provided substantial financial support for the new building at the Sherman Station. We also installed new cabinets in the agronomy and weed science lab, purchased a GSRTS tractor, 3 pt mount coring and drilling machine for soil probing for the agronomy program, and purchased a 220 volt compressor for the new storage building at Pendleton. The boiler for the greenhouse was removed and the ongoing building renovation was continued.

The ARS installed a concrete wash pad in the equipment yard, replaced the shop HVAC, the well pump, and re-roofed the storage room in the annex. Energy-saving light fixtures were installed in the main office building and the lighting in the storage warehouse was improved. The break room was relocated and improvements were made to the Microbiology Laboratory. Other upgrades included new laboratory faucets and handicap-accessible drinking fountains. The ARS equipment purchases the past year included a used combine and 12' flail, a combination heavy harrow and sickle mower, air reel and yield monitor, a gravity table, a turbidity monitoring station with digital data acquisition capabilities, a digital soil temperature monitoring array, crew cab diesel pickup truck, and a hillside combine fitted with a GPS-linked yield monitor. Laboratory equipment purchases included programmable fraction collector, water bath, a digital platform shaker, a carbon dioxide transmitter, and syringe pump. The equipment acquisitions were made with considerable assistance from the USDA-ARS Pacific West Area.

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.

All USDA staff licensed to apply pesticides completed recertification training. All staff received updates on cardio-pulmonary resuscitation, first aid, ethics, sexual harassment prevention, and civil rights training. John Robertson, Fire Officer from the Umatilla National Forest, presented Fire Safety Training to the staff. ARS Staff participated in a SAIFer driver education course. Linda Baugh and Tami Johlke attended Hazardous Material Training for Public Employees; Linda Baugh received OSHA 600 Collateral Duty Safety training; and Amy Baker went to a four-day Laboratory Safety & Health training course. Amy Baker, Rich Greenwalt, and Scott Oviatt completed a three-day Arcview Workshop, and Marty Platt completed a one-day Excel workshop. Tami Johlke attended a two-day Riparian Workshop. John Williams went to Supervisory Academy, and Steve Albrecht attended a Seminar for New Managers.

Visitors

The Center hosted several special events, including numerous research and planning meetings.

Visitors hosted by the staff at the center included:

Mike Ferguson, Pendleton, OR
Greg Goad, Oregon Wheat Growers League, Pendleton, OR
Margaret Jacobs, Oregon State University, Corvallis, OR
Larry Coppock, Adams, OR
Aaron Jackson, Confederated Tribes of the Umatilla Indian Reservation, Pendleton, OR
Mike Ladd, OWRD, Pendleton, OR
Brad Baugh, USDA-ARS, Pullman, WA
Tom Darnell, Oregon State University Extension Service, Milton-Freewater, OR
Walt Gary, Walla Walla County Extension, Washington State University, Walla Walla, WA
Lori Brogoitti, Pendleton, OR
Fred Kubrock, Tektonics Corporation, Walla Walla, WA
Alan Wernsing, Athena, OR
Matt Whiting, Cranbrook, British Columbia
Joerg Lehmann, Cranbrook, British Columbia
Russ Storey, Kennewick, WA
Ernie Fontana, Richland, WA
Kay Simpson, Pendleton, OR
Larry Bishop, Milton-Freewater, OR
Mark Hales, Adams, OR
Robert Newtson, Helix, OR
Jessica Pottenger, Smith Frozen Foods, Weston, OR
Don Drader, Moses Lake, WA
Mark Hales, Adams, OR
Bart Brinkman, Salem, OR
James Bronson, Confederated Tribes of the Umatilla Indian Reservation, Pendleton, OR
A Wildbill, Confederated Tribes of the Umatilla Indian Reservation, Pendleton, OR
Donna Nez, Confederated Tribes of the Umatilla Indian Reservation, Pendleton, OR
Jim Davis, PSES Department University of Idaho, Moscow, ID
Brad Bull, PSES Department University of Idaho, Moscow, ID
Scott Tullis, Hermiston, OR
Tyler Hansell, Hermiston, OR
Randy Mills, Umatilla County Extension Service, Pendleton, OR
Beth Mills, Agri-Times NW, Pendleton, OR
Jim Burns, Milton-Freewater, OR
Mat Kolding, Pendleton, OR
Karl Niederwerfer, Pendleton, OR
Richard Kirkava, Senator Gordon Smith's Office, Pendleton, OR
Senator Gordon Smith, Pendleton, OR
Karl Scronce, Klamath Falls, OR
Phillip Zurbrick, La Grande, OR
Tammy Dennee, Oregon Wheat Growers League, Pendleton, OR
Ken Grieb, Oregon Wheat Growers League, Pendleton, OR
Andy Vanderplatt, Farm Credit Services,

Pendleton, OR

Bill Hansell, Umatilla County Commission, Pendleton, OR

Chris Rauch, Lexington, OR

Scott Peters, Wasco, OR

Alice Voluntad, OSU Extension Service, Pendleton, OR

Dan Clark, Athena-Weston School District, Athena, OR

Mayor Bob Ramig, Pendleton, OR

Larry Lutcher, Morrow County Crops Agent, Oregon State University, Heppner, OR

Tom Straughan, Umatilla Soil and Water Conservation District, Water Quality Planner for Oregon Department of Agriculture, Pendleton, OR

Ray Denny, Umatilla Soil and Water Conservation District, Pendleton, OR

Clinton Reeder, USDA Air Quality Council, Umatilla Basin Watershed Council, Pendleton, OR

Kate Ely, Confederated Tribes of the Umatilla Indian Reservation, Pendleton, OR

Dr. Antoinette Betschart, Area Director, USDA-ARS, Albany, CA

Joe Garbarino, Director of Budget and Program Management, Beltsville, MD

Marshall Tarkington, Senior Legislative Analyst, Beltsville, MD

Hank Moore, House Staff member for House Agriculture Appropriations, Beltsville, MD

Donna Erickson, PSES Department University of Idaho, Moscow, ID

Jack Brown, PSES Department University of Idaho, Moscow, ID

Duane Johnson, Experiment Station, Kalispell, MT

Chris Mundt, Botany & Plant Pathology, Oregon State University, Corvallis, OR

Whitman College Biology Class, Walla Walla, WA

Roland Schirman, Columbia County Extension, Dayton, WA

Dick Deshane, Columbia County Extension, Dayton, WA

Evan Canfield, USDA-ARS Hydrologist, Southwest Watershed Research Center, Tucson, AZ

Johannes Lehmann, Cornell University, Ithaca, NY

Andrea Redman, Graduate Student, Oregon State University, Corvallis, OR

David Close, Confederated Tribes of the Umatilla Indian Reservation, Pendleton, OR

Craig McNeal, Imbler, OR

Scott Counsell, La Grande, OR

Kim Campbell, USDA-ARS, Pullman, OR

Randy Scott, Gustafson, Boise, ID

Jay Gehrett, Velsicol Chemical Corp, Walla Walla, WA

Corey McAllister, Oregon Vocational Rehab Services, Pendleton, OR

Thayne Wiser, Wiser Farms, Tri-Cities, WA

Bud Schmidtgall, Athena, OR

Mary Corp, Umatilla County Extension Service, Pendleton, OR

Lisa Lang, Enterprise, OR

Joan Silver, Kimberly, OR

Gary Thompson, Moro, OR

Loren Unruh, USDA-NRCS, Heppner, OR

Jim Loiland, NRCS, Pendleton, OR

Matt Wood, Helix, OR

Kevin Hudson, Pendleton, OR

Pat and Trudy Maney, Helix, OR

Jordan Maley, Gilliam County Extension Service, Condon, OR

Jim Straughan, Pendleton, OR

Pat Straughan, Pendleton, OR

Ken Thompson, Helix, Or

Bryan Jones, Helix, OR

Guy Hopkins, Umatilla County Soil & Water Conservation District, Pendleton, OR

Thomas Endicott, Eugene, OR

Greg Chilcote, Extension Computing, Oregon State University, Bend, OR

Xianming Chen, Plant Pathology, Washington State University, Pullman, WA

Berk Davis, B.L. Davis Ranch, Adams, OR

Sandy Halstead, EPA, Prosser, WA
Barbara Minton, Department of Environmental Quality, Pendleton, OR
Dr. Jae Molina, University of Minnesota, St. Paul, MN
Nicole Kerr, Department of Agriculture, Western Australia
Steven Dodrill, Extension & Experiment Station Communications, Oregon State University, Corvallis, OR
Mary Ann Hill, Pendleton, OR
John Anderson, Umatilla County ESD, Pendleton, OR
Caty Clifton, United States Forest Service, Pendleton, OR
Bill Peal, Pendleton, OR
Japanese Tour Group
Mary Verhoeven, Oregon State University, Corvallis, OR
Mark Larson, Oregon State University, Corvallis, OR
Jim Peterson, Oregon State University, Corvallis, OR
Darrin Walenta, Union County Extension, La Grande, OR
Marty King, Soil and Water Conservation District, Pendleton, OR
Kaito Morita, Sakura, Japan
Don McCool, USDA-ARS, Pullman, WA
John Morse, USDA-ARS, Pullman, WA
Bill Bowe, Biological Systems Engineering, Washington State University, Pullman, WA
Khalid Alui, Biological Systems Engineering, Washington State University, Pullman, WA
Bart Duff, Adams, OR
Laterne McDonald, Australia
Virginia Tubbs, Adams, OR
Jay Gibbs, NRCS, Heppner, OR
Jeff Steiner, ARS, Oregon State University, Corvallis, OR
Toshimi Minoura, Computer Science, Corvallis, OR
Teerawat Wuttiwat, Computer Science, Corvallis, OR
Shannon Denton, Pendleton, OR
Cheryl Shippentower, Pendleton, OR
Ryan Bransetter, Pendleton, OR
John Sheldon, Kalispell, MT
Ray Hussle, USDA-CRI
Todd Harrington, USDA-CRI
Kelly Huynh, USDA-CRI
Jen Barrir, USDA-CRI
Rick Holman, USDA-CRI
Gil Cook, DuPont, Greenacres, WA
Thomas League, BCD, Salem, OR
Bob Christ, Oregon State University, Corvallis, OR
Greg Henderson, Irrigon, OR
Jim Davis, University of Idaho, Moscow, ID
Russ Karow, Oregon State University, Corvallis, OR
Mary Veerhoeven, Oregon State University, Corvallis, Or
Rick Ackerman, Spokane, WA
Pete and Rebecca McNally, Klamath Falls, OR
Tara Simpson, Portland, OR
Dave Walt, Confederated Tribes of the Umatilla Indian Reservation, Pendleton, OR
Joan Wu, Washington State University, Pullman, WA
Shuhui Dun, Washington State University, Pullman, WA
Ken Schroeder, Pilot Rock, OR
Bryan Allstott, Hermiston, OR
John Morse, USDA-ARS, Pullman, WA
David Wolf, Confederated Tribes of the Umatilla Indian Reservation, Pendleton, OR

Seminars

The 2002 OSU/ARS seminar series at the Centers was coordinated by Chengci Chen and Don Wysocki. Seminars included the following speakers and topics:

Problems, Challenges, and Opportunities with

Chemical Fallow, Dr. Larry Lutcher, Morrow County Crops Agent, Oregon State University, Heppner, OR, 17 April.

Modeling Erosion and Sediment Transport at the Los Alamos National Laboratory in the Wake of the Cerro Grande Fire, Dr. Evan Canfield, USDA-ARS Hydrologist, Southwest Watershed Research Center, Tucson, AZ, 14 May.

ARS Weather Data Acquisition and Dissemination, Mr. H. Scott Oviatt, USDA-ARS, Columbia Plateau Conservation Research Center, Pendleton, OR, 23 May.

Biogeochemical Cycling of Sulfur and Its Interaction with Carbon in Long-term Agroecosystems Experiments, Dr. Johannes Lehmann, Assistant Professor, Cornell University, Ithaca, NY, 18 October.

Dynamics of Phosphorus and Sulfur Nutrition of Direct Seeded Spring Wheat using PRS Soil Probes, Andrea Redman, Graduate Student, Oregon State University, Corvallis, OR, 5 December.

Pacific Lamprey Research and Restoration Project, David Close, Confederated Tribes of the Umatilla Indian Reservation, Pendleton, OR, 23 January.

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

Liaison Committees

The Pendleton and Sherman Liaison Committees were led by chairpersons Mark Hales and Ernie Moore, 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 wishes to express their appreciation to individuals, associations, and corporations who have given special assistance for the operation of experimental plots on or associated with the centers during this past year 2002-2003. 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:

Agrium,
BASF Corp.,
Bayer Corp.,
Leonard (Buckshot) Carter,
Community Corrections Work-Release Program,
E.I. du Pont de Nemours,
FMC Corp.,
Richard Lieuallen,
Terry Mayberry,
Richard (Mac) McDonough,
Monsanto Co.,
Tom Neidlinger,
Paul Pargeter,
Pendleton Grain Growers,
Rohm and Haas,
Al Sartini,

Stubbs Seed Service,
Zeneca Ag Products,
Jim Els, Brad Murison, Cal Gilmer, and Amund Melville, Sprague Grange, Harrington, WA,
Judy, Keith and Gary Rea, Ione, OR,
Mrs. John Kerege and Louie Kerege, The Dalles, OR,
Steve Peck, manager, Roger Campbell Property, Lexington, OR,
David Brewer, The Dalles, OR,
Bob Olsen, Moro, OR,
Ernie Barnett, Mikkalo, OR,
Pat Davis, Adams, OR,
Bob Hopper, Adams, OR,
Gary McNab, Wasco, OR,
Raymond Reeder, Pendleton, OR,
Louis Carlson, Heppner, OR,
Ms. Vivian Todd, Grass Valley, OR,
Kenneth Hattrup, The Dalles, OR,
Ken Thompson, Helix, OR,
Bryan Jones, Helix, OR,
Scott Harper, Pendleton, OR, and
Leon Reese.

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,
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, and
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:
Columbia River Bank,
Farm Credit Service,
Gustafson,
Klamath First Federal,
Mid-Columbia Bus Co.,
Mid Columbia Producers,
Monsanto Co.,
Morrow County Grain Growers,
Pioneer Implement,
Richelderfer Air Service,
Safeway,
Sherman Aviation,
Sherman County High School,
Wasco Electric Coop., and
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, Jeff McMorran, 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; Bill Schillinger in Adams/Lincoln Counties; Walt Gary in Walla Walla County; and John Burns in Whitman County.

We wish to express special gratitude to the 45 farmers 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 would also like to thank the Umatilla Soil and Water Conservation District, Bev Kopperud, Ray Denny, and Felicity Dye for their continued support.

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

Steve Petrie
Superintendent
OSU-CBARC

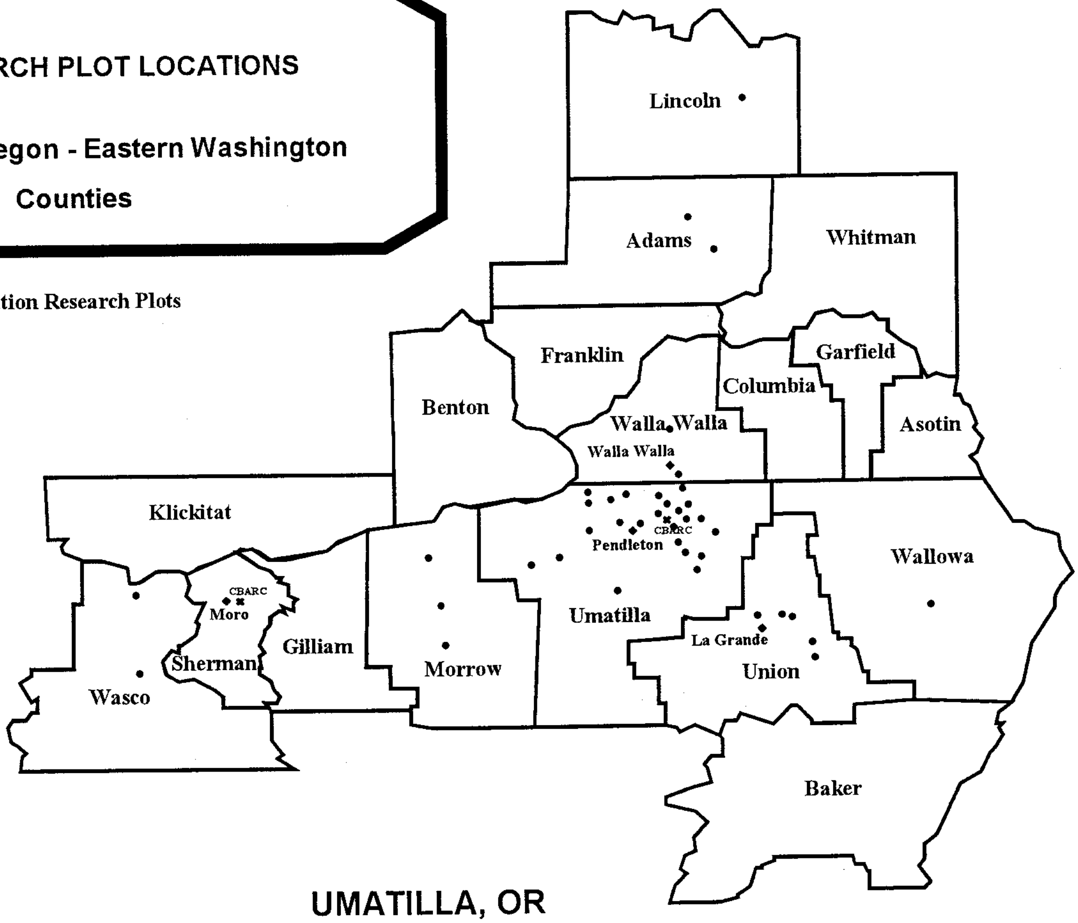
Stephan Albrecht
Acting Research Leader
USDA-ARS-CPCRC

RESEARCH PLOT LOCATIONS

Eastern Oregon - Eastern Washington

Counties

• Off-Station Research Plots



ADAMS, WA

Curtis Hennings
Bill Schillinger
WSU Dryland Experiment Station

LINCOLN, WA

Jim Els

WALLA WALLA, WA

Dwellie Jones
Guy McCaw

UMATILLA, OR

John Adams
Charles Betts
Bracher Farms
Cliff Bracher
Larry Coppock
D-8 Ranches
Davis Farms
Berk Davis
Mary Ann Davis
Jim Duff
Greg Goad
Phil Hawman
Mark Kirsch
Jim Loiland
Bill Lorenzen
Pat Lyon
Suzy Lyon
Tracy Lyon
Kent Madison
Pat Maney
Gary Nibler
Les Owen
Fred Price
Clint Reeder
Paul Reeder
Leon Reese
Sherman Reese

UNION, OR

Dale Case
Rod Case
John Cuthbert
Roger Davis
Sonny Johnson

MORROW, OR

Kelwayne Haugewood
William and Nancy Jepsen
Chris Rauch

WALLOWA, OR

Kurt Melville
Tim Melville

WASCO, OR

Jack Hay
Bill Johnson
John McElheran

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FERTILIZER MANAGEMENT FOR WINTER MALTING BARLEY

Steve Petrie, Pat Hayes, Karl Rhinhart, Nathan Blake, Jennifer Kling, and Ann Corey

Abstract

Winter malting barley offers dryland growers in northeastern Oregon a potential alternative crop. However, there is very limited information available on the fertilizer requirements of winter barley. The objectives of this research were to evaluate the response of adapted winter feed barley varieties and advanced winter malting barley lines to nitrogen (N), phosphorus (P), zinc (Zn), and chloride (Cl) fertilization at Pendleton and Moro. Nitrogen fertilization increased plant height, grain yield, grain protein, and thin kernels, and reduced test weight and plump kernels. There was no response to P fertilization at either location but Zn fertilization increased flag leaf Zn concentration and tended to increase test weight and kernel plumpness at Moro. Fertilization with Cl increased flag leaf Cl concentration and grain yield at both sites and increased test weight and plump kernels at Pendleton.

Key words
barley yield, Cl fertilizer, malting barley quality, N fertilizer management, P fertilizer, Zn fertilizer

Introduction

The development of a superior quality, well-adapted winter malting variety will offer growers in northeastern Oregon a profitable potential alternative crop. Winter malting barley lines suitable for production in eastern Oregon are being developed at Oregon State University (OSU). The most promising of these lines are currently undergoing evaluation for malting and brewing quality. We are evaluating the response of these lines to various agronomic variables in this research program. This report will discuss the nitrogen (N), phosphorus (P), zinc (Zn), and chloride (Cl) management component of the program.

The malting and brewing industry is driven by quality, perhaps more so than any other cereal-based industry. Two key quality factors include kernel size distribution and grain protein. Maltsters and brewers desire grain that is uniformly sized with at least 70 percent plump kernels (retained on a 6/64 screen) and less than 5 percent thin kernels (passing through a 5/64 screen). This kernel size uniformity promotes uniform water inbibition and the subsequent germination and attendant chemical and biological changes are more uniform. Grain plumpness is measured on each load of grain from the field as it is delivered to the elevator or receiving station. Grain that does not meet the plumpness standard is immediately rejected, substantially reducing the value to the grower.

The key factor that determines malting barley quality is grain protein. Grain with excessively high or low protein levels results in unacceptable malt quality. Six-row malting barley should have from 11.5 to 13.5 percent protein. In many other production areas, the major grain quality issue is excessively high protein levels and growers are challenged to produce grain with protein levels less than 13.5 percent. This is especially true in irrigated regions where other high value, highly N-fertilized crops are commonly grown in rotation with malting barley. The high rates of N fertilization often lead to excessively high grain protein levels. In contrast, dryland crop growers have less incentive to apply high rates of N fertilizers and growers must often resort to N management strategies designed to increase grain protein.

New barley varieties are being developed and their yield and grain protein response to N fertilizer have not been evaluated. Determining the effect of N management on grain protein and quality in advanced barley lines will permit us to make informed decisions about these lines prior to public release.

Results from fieldwork in the 2000-01 growing season indicated that we could manipulate N application and timing to affect grain protein and quality (Petrie et al. 2002). In the 2000-01 growing season, the greatest yields were achieved when 50 to 100 lbs of N was applied in the fall. Preplant soil testing revealed about 120 lbs of N per acre in the top 5 feet of the soil profile. Applying an additional 50 lbs of N per acre in the spring had little effect on grain yield when 50 or 100 lbs of N per acre was applied in the fall. In contrast to the grain yield, there was a linear increase in grain protein from about 9 percent with no fall N fertilization to about 12 percent when 150 lbs of N was applied in the fall.

Although N is the most widely deficient nutrient, other nutrients such as P, Zn, and Cl may also limit cereal yields. There is little information on the P fertilizer requirements of winter malting barley, although we are using the fertilizer guides for winter wheat as a starting point. There is even less information on Zn fertilizer guidelines for winter wheat and essentially no information for winter malting barley. The soil test values for Zn range from 0.2 to about 1.0 ppm at the Moro and Pendleton stations of CBARC. These values are near or below the commonly accepted critical soil test nutrient levels; however, there has been little field research on Zn to validate the soil test levels that are needed for high yields of top quality malting barley. Finally, there is evidence that Cl fertilization may be beneficial to cereals such as wheat and barley. For example, Smiley (1993) reported that foliar application of a Cl-containing fertilizer reduced the incidence of physiologic leaf spot. However, there has not been any previous work on Cl and its potential role in plant nutrition at CBARC.

The objectives of this research were to evaluate the effects of increasing N application rates and split N applications on plant height, grain yield, grain protein, and plumpness of four winter barley varieties and three advanced winter barley lines. This research also examined the response to P, Zn, and Cl by several lines of potential malting barley varieties.

Materials and Methods

N Rate and Timing at Pendleton

Four winter feed barley varieties ('Hundred', 'Kold', 'Scio', and 'Strider') and three winter malting barley lines ('Stab 7', 'Stab 47', 'Stab 113') were seeded on October 2, 2001 at the Pendleton Station using a five-row Hege cone seeder with disk openers on 12-in row spacing. Soil samples collected prior to seeding were analyzed and the results are shown in Table 1. Preplant N was applied at 0, 50, 100, or 150 lb N/acre as urea using a Hege drill with a nine-row cone seeder. The fertilizer was placed about ½ in deep in the soil. The entire trial area received 100 lb K_2SO_4 per acre to supply K and S and 80 lb P_2O_5/acre as triple superphosphate (0-45-0). Individual treatments received an additional 50 lb N as urea using the Hege cone seeder on March 5, 2001 when the plants were in the four-leaf stage of development. The trial was arranged as a randomized complete block design with four replications. Plant height was measured and the plots were harvested using a Hege plot combine. The grain from the plots was weighed and subsamples collected for determination of test weight, grain protein, and percent plump and thin kernels.

P and Zn trials

A promising winter malt barley line ('Stab 47') was seeded at Pendleton on October 5, 2001 and at Moro on October 11, 2001 using a five-row Hege cone seeder. Pre-plant soil test values are shown in Table 1. Phosphorus was applied at 0 or 40 lb P_2O_5 per acre as triple superphosphate (0-45-0) and Zn was applied at 0 or 5 lb Zn per acre as zinc sulfate; the fertilizer was placed directly with the seed at planting. The entire plot area received 100 lb K_2SO_4 per acre to supply K and S and either 80 lb N per acre (Pendleton) or 50 lb N per acre (Moro) as anhydrous ammonia. The trial was arranged as a randomized complete block design with four replications. Flag leaf samples were collected at heading and analyzed for P and Zn. The plots were harvested using a Hege plot combine. The grain from the plots was weighed and subsamples collected for determination of test weight, and percent plump and thin kernels.

Cl Trials

'Strider' winter-feed barley and 'Stab 47', a winter malting barley, were seeded at Pendleton on October 5, 2001 and at Moro on October 11, 2001 using a five-row Hege cone seeder. Pre-plant soil test values are shown in Table 1. Chloride was applied at 0, 50, or 250 lb per acre as KCl. The treatments were broadcast on the soil surface immediately after seeding. The trial was arranged as a randomized complete block design with four replications. The entire area received 80 lb N per acre and 15 lb S per acre as a mixture of anhydrous. 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 and subsamples collected for determination of test weight, and percent plump and thin kernels.

Table 1. Preplant soil test values at Pendleton and Moro, 2001-02

Site and Trial	pH	N[1]	P	K	SO_4	Zn	Cl
		---------- ppm ----------					
Pendleton							
N rate	6.2	30	21	458	9	0.8	10.6
P x Zn, Cl	6.6	26	13	393	9	0.4	10.6
Moro							
P x Zn, Cl	6.5	18	28	362	4.6	0.4	4.0

[1]N values represent the total N ($NO_3 + NH_4$) in the top 4 ft of the profile.

Results and Discussion

N Rate and Timing Trial at Pendleton

Plant Height

Averaged across the seven varieties and lines in the study, increasing the rate of fall-applied N increased the plant height from 32 to 36 in (Fig. 1). Spring N application increased average plant height when no N was applied in the fall but had no effect on plant height when 150 lb N was applied in the fall. These results were not consistent across varieties. 'Stab 113', the most promising advanced line, exhibited a somewhat different plant height response to N fertilizer. Plant height increased only two in as the fall N rate increased from 0 to 150 lb N per acre. In contrast, spring N application increased the plant from 30 to 36 in at increasing rates of fall N. The plants were somewhat shorter in 2001-02 compared to 2000-01; the average plant at the highest rate of N was about 39 in. in 2000-01 and only 36 in. in 2001-02. There was no lodging in this trial regardless of the N application rate or time of application.

Grain Yield

There was only a small grain yield response to fall applied N fertilizer (Fig. 2). Averaged across the varieties and lines in the study, the yield response was only about 500 lb per acre and the greatest yield was obtained with 50 lb N per acre. Applying 50 lb N in the fall resulted in about 5,000 lb of grain regardless of the amount of N applied in the fall. 'Strider' produced the greatest yield with almost 6,200 lb of grain per acre. These results are similar to the results from the 2000-01 crop year; the largest yields were produced with 50-100 lb N per acre in the fall

Test weight

Increasing the rate of fall applied N reduced the average test weight from 52.4 to 51.4 lb per bushel (Fig. 3). Applying 50 lb N in the spring reduced the average test weight as well. 'Stab 113' responded quite differently to the added N; the test weight increased as fall N application rate increased up to 100 lb N per acre but then fell slightly when 150 lb N was applied in the fall. The test weight was about 1 percent less when an additional 50 lb N was applied in the spring.

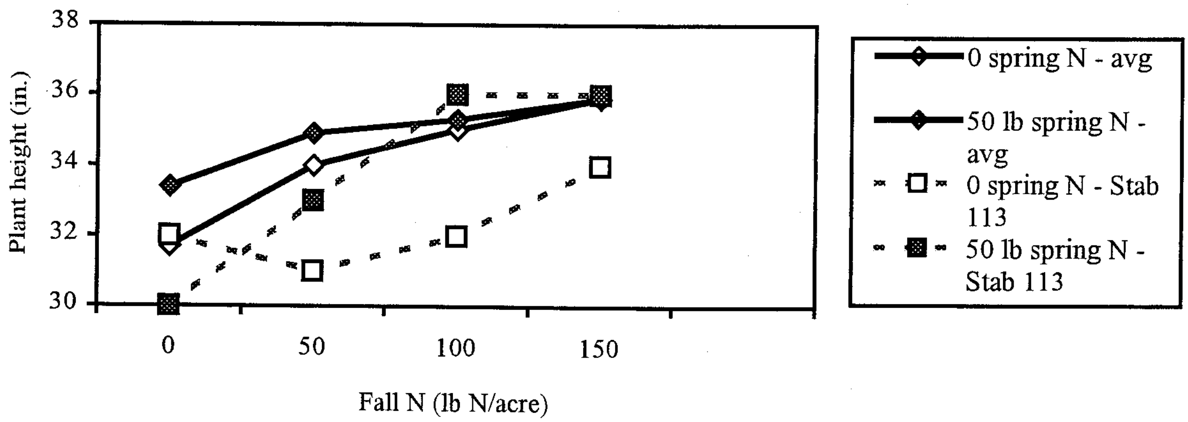

Figure 1. Effects of fall and spring N applications on average plant height of seven varieties and advanced lines of winter barley at Pendleton, 2001-02.

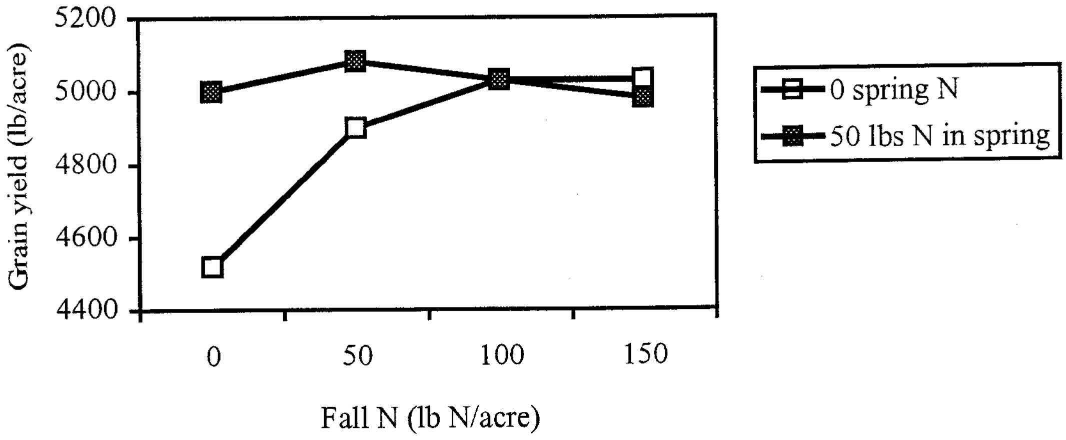

Figure 2. Effects of fall and spring N application on the yield of seven varieties and lines of winter barley at Pendleton, 2001-02

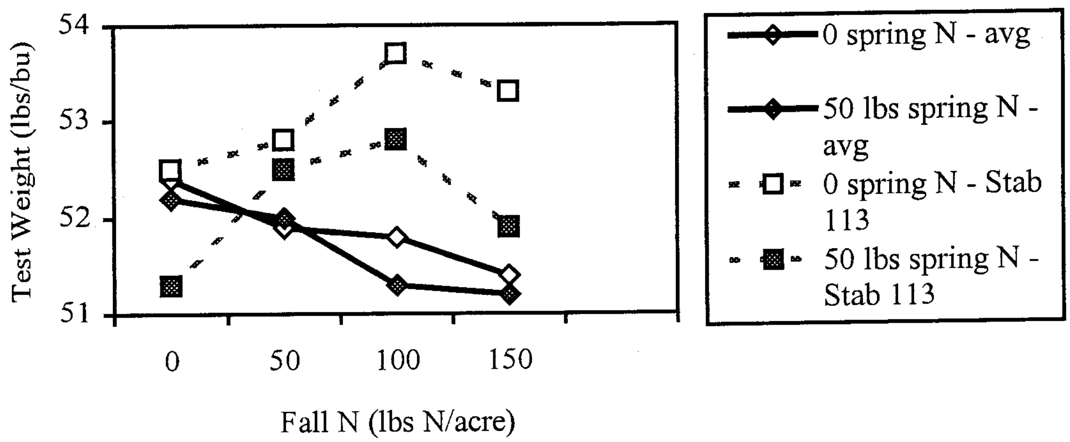

Figure 3. Effects of fall and spring N on average test weight of seven varieties and advanced lines of winter barley at Pendleton, 2001-02.

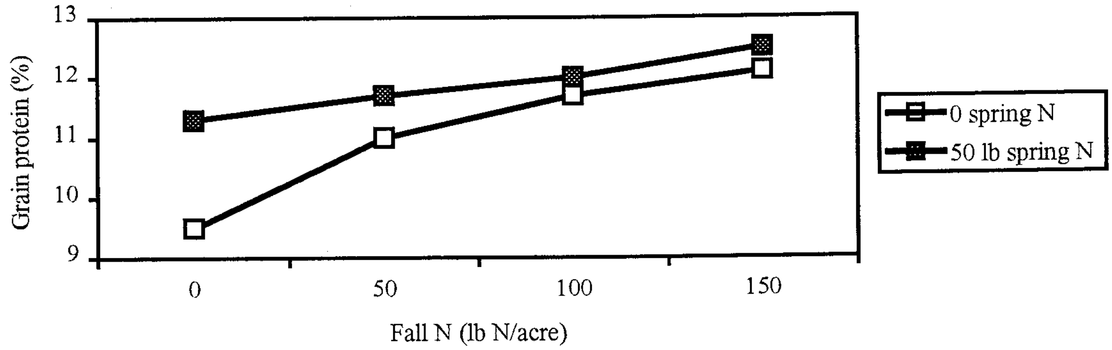

Figure 4. Effects of fall and spring N on grain protein in two advanced lines of winter malting barley at Pendleton, 2001-02

Grain protein

Average grain protein increased as the rate of fall N increased (Fig. 4). These values represent 'Stab 7' and 'Stab 113' malting barley lines as grain protein was not measured in the feed barley grain samples. These results are similar to the results from the 2000-01 crop year. The grain protein increased linearly about 1 percent for each additional 50 lb N per acre in 2000-01. The grain protein in this trial increased about 1.5 percent when the first 50 lb N per acre was applied but only about 0.5 percent when the N application rate was increased from 100 to 150 lb N per acre. Spring N applications increased grain protein but the magnitude of the increase was reduced as greater amounts of N were applied in the fall. A split application of fall and spring N was no more effective than a fall application of the same total amount of N. For example, application of 50 lb N per acre in the spring with 50 lb N per acre in the fall produced the same grain protein as applying 100 lb N per acre in the fall.

Plump kernels

The average percentage of plump kernels was decreased from 59 to 41 percent as the rate of fall N increased from 0 to 150 lb N per acre (Fig. 5). Applying an additional 50 lb N per acre in the spring resulted in about 3 percent fewer plump kernels. There were marked differences between the varieties and lines examined in this study. 'Stab 113', for example, tended to have more plump kernels and was less affected by increasing N application rates. The percentage of plump kernels in 'Stab 113' fell only 7 percent, from 70 to 63 percent, as the fall N rate increased from 0 to 150 lb N per acre.

Thin kernels

Increasing the fall N application rate increased the average percentage of thin kernels (Fig. 6). Each added increment of N increased the thin kernels about 1 percent. Applying 50 lb N in the spring increased the average thin kernels about 1 percent.

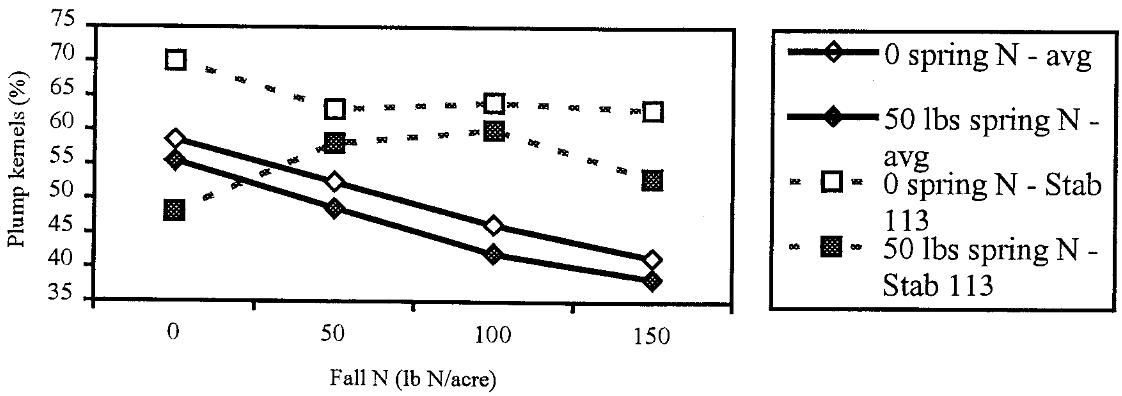

Figure 5. Effects of fall and spring N on average plump kernels of seven varieties and advanced lines of winter barley at Pendleton, 2001-02.

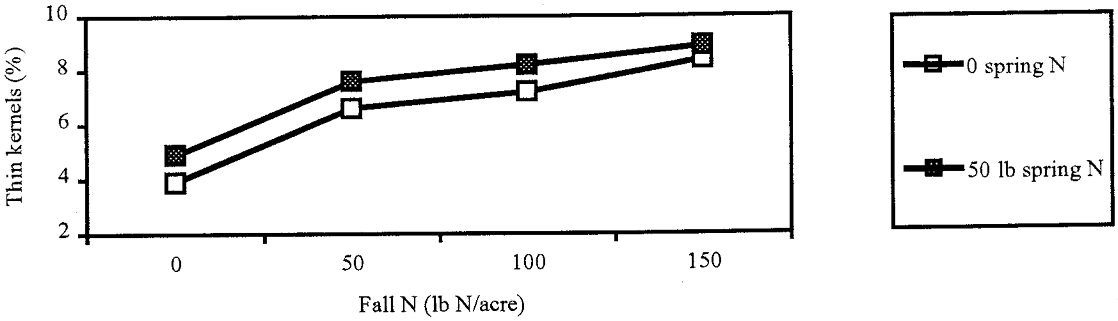

Figure 6. Effect of fall and spring N applications on average thin kernels of seven varieties and advanced lines of winter barley at Pendleton, 2001-02.

P and Zn trials

The soil test values for Zn concentration at both Pendleton and Moro were 0.4 ppm; soil test levels less than 0.6 to 0.8 ppm are commonly considered to be deficient for many crops although there are no soil test correlation data for winter barley in Oregon.

Pendleton

The application of P and Zn fertilizer had little effect on leaf P concentration, grain yield, test weight, or kernel size distribution (Table 2). Application of Zn fertilizer significantly increased the Zn concentration in the flag leaf from about 15 to 22 ppm. Jones (1991) indicated that less than 15 ppm Zn in leaves may indicate a Zn deficiency but also stated that less than 20 ppm Zn in leaves may be deficient. These Zn leaf levels are in the range that Jones (1991) indicated may be deficient but there was no yield response to Zn fertilization.

Moro

The application of P and Zn fertilizers had no effect on barley yield at Moro but did affect several other parameters (Table 3). Application of P and Zn fertilizers tended to increase leaf P and Zn concentration when both P and Zn were applied together. Fertilization with Zn significantly increased test weight and plump kernels and reduced thin kernels when P was not applied. Thus, Zn application appears to be having a beneficial effect on some grain quality characteristics.

Table 2. Effects of P and Zn on P and Zn concentration in flag leaf, grain yield, test weight, and kernel size of Stab 47 winter malting barley at Pendleton, 2001-02.

Treatment		Flag leaf conc.		Grain	Test	Kernel size	
P_2O_5	Zn	P	Zn	yield	wt.	Thin	Plump
---- lb/acre ----		%	ppm	lb/acre	lb/bu	--------- % ---------	
0	0	0.24	17	4,540	51.7	3	71
0	5	0.26	22	4,155	51.6	2	73
40	0	0.22	15	4,320	51.4	3	73
40	5	0.24	21	4,470	51.8	3	71
$LSD_{0.10}$		0.03	3	325	0.5	1	4

Table 3. Effects of P and Zn on P and Zn concentration in flag leaf, grain yield, test weight, and kernel size of Stab 47 winter malting barley at Moro, 2001-02.

Treatment		Flag leaf conc.		Grain yield	Test wt.	Kernel size	
P_2O_5	Zn	P	Zn			Thin	Plump
---- lb/acre ----		%	ppm	lb/acre	lb/bu	--------- % ---------	
0	0	0.21	16	3,190	47.0	8	46
0	5	0.23	17	2,985	48.5	5	58
40	0	0.23	17	3,140	48.0	6	55
40	5	0.24	20	3,085	49.0	5	59
$LSD_{0.10}$		0.03	4	215	1.3	3	9

Cl Trials

There are no soil test correlation data for Cl in Oregon but reports from other regions indicate that less than about 10 ppm may be associated with Cl fertilizer responses.

Pendleton

Chloride application dramatically increased leaf Cl concentration of both 'Strider' and 'Stab 47' and significantly increased grain yield of 'Strider' (Table 4). It should be noted that the grain yield of 'Stab 47' was lower in this trial than in the N rate study where 'Stab 47' produced almost 4,300 lb of grain when it received 100 lb N in the fall. There was a tendency for Cl applications to increase test weight for both 'Strider' and 'Stab 47' and Cl application significantly increased the plump kernels in 'Stab 47'.

Table 4. Effect of Cl fertilization on flag leaf Cl concentration, grain yield, test weight and kernel plumpness of winter barley at Pendleton, 2001-02.

Cl rate	Flag leaf Cl		Grain yield		Test weight		Plump kernels	
	Strider	Stab 47	Strider	Stab 47	Strider	Stab 47	Strider	Stab 47
lb/ac	------ ppm ------		----- lb/acre ----		----- lb/bu ------		---------- % --------	
0	2,650	2,710	4,980	3,860	51.3	50.9	86.5	61.7
50	4,180	3,950	6,400	3,745	52.6	51.3	88.5	80.2
250	6,420	7,405	5,890	3,700	52.4	51.2	89.5	78.7
$LSD_{0.10}$	650		840		0.8		10	

Moro

Chloride application significantly increased flag leaf CL concentration and grain yield of both 'Strider' and 'Stab 47' (Table 5). The test weights and kernel plumpness tended to be less at Moro than at Pendleton due to the drier conditions during the growing season. Test weight and kernel plumpness did not respond to Cl fertilization.

Summary

The application of N fertilizer increased plant height, grain yield, grain protein, and thin kernels and reduced test weight and kernel plumpness. Soil test Zn values at both Pendleton and Moro were less than the commonly accepted deficient values but Zn applications had no positive effects on yield at either location; Zn application did increase test weight and kernel plumpness at Moro. Phosphorus application had no beneficial effects at either site. Chloride fertilization increased leaf Cl concentration in both 'Strider' and 'Stab 47' at both locations and increased grain yield of 'Strider' at both sites and 'Stab 47' at Moro.

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Table 5. Effect of Cl fertilization on flag leaf Cl concentration, grain yield, test weight, and kernel plumpness of winter barley at Moro, 2001-02.

Cl Rate	Flag leaf Cl		Grain yield		Test weight		Plump kernels	
	Strider	Stab 47	Strider	Stab 47	Strider	Stab 47	Strider	Stab 47
lb/ac	------ ppm ------		----- lb/acre ----		----- lb/bu -----		---------- % --------	
0	3,720	3,350	3,220	2,950	47.5	49.7	52.3	60.0
50	7,460	6,575	3,550	3,245	47.3	49.5	57.0	60.7
250	10,836	9,910	3,640	3,285	48	49.7	56.3	59.3
$LSD_{0.10}$	1,660		305		1.7		10	

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VARIETY, SEEDING DATE, SPACING, AND SEEDING RATE EFFECTS ON GRAIN YIELD AND GRAIN SIZE OF CHICKPEAS (*CICER ARIENTINUM* L.) IN EASTERN OREGON

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

Abstract

The effects of seeding chickpea (*Cicer arientinum* L.) varieties, 'Dwelley' and 'Sinaloa', at different dates, spacing, and rates were evaluated at sites that receive 11 in (Sherman Experiment Station, Moro), 15 in (Columbia Basin Agricultural Research Center [CBARC], Pendleton) and 20 in (Nibler's Farm, Milton-Freewater) of precipitation. At all sites, the highest grain yields were produced when both varieties were seeded in early April. Seeding after early April substantially reduced grain yields. 'Dwelley' produced a higher yield than 'Sinaloa' only when planted in early April at the Nibler Farm where precipitation is >20 in. At the sites receiving 11 and 15 in, 'Sinaloa' produced a significantly higher yield than 'Dwelley' at all the planting dates, indicating that 'Sinaloa' is more drought tolerant than 'Dwelley'. Although plants seeded in early April were most affected by diseases caused by *Fusarium* and viruses, they produced the highest grain yields. The grain size of 'Dwelley' decreased when planting occurred after the first week of April, but the grain size of 'Sinaloa' was less affected. At the Nibler Farm, grain yields of both varieties increased when the seeding rate was increased from 1.5 to 3 seeds/ft^2; no further response was obtained by increasing seeding rates to 4.5 seeds/ft^2. At Pendleton and Moro, increasing the seeding rate from 1.5 to 4.5 seeds/ft^2 significantly increased the grain yield of 'Sinaloa'. The yield of 'Dwelley' did not respond to seeding rates above 3 seeds/ft^2. The grain yields of 'Sinaloa' were significantly higher than the yields of 'Dwelley' at all seeding rates. Row spacing did not influence grain yields of either variety at all sites. These results are preliminary and the experiment will be repeated in 2003.

Key words

Chickpea, row spacing, seeding date, seeding rate

Introduction

Although research on chickpea (garbanzo) dates back to the 1940's and 1960's, it is a relatively new commercial legume crop to northeastern Oregon and limited information on chickpea agronomy exists for this region. At a recent grower meeting, many questions on chickpea production were raised. Areas of greatest concern included varieties, seeding dates, and plant density, among other topics. The goal of this work is to address these concerns.

Precipitation in the Pacific Northwest (PNW) is highest during winter and lowest in summer. Thus, chickpea, which is planted in the spring, matures on decreasing water supply and residual moisture. The date the crop is seeded determines how much water will be available for the crop, with more water being available for the early- than the late-seeded crop. Therefore, seeding early in the spring ensures adequate moisture for optimum plant growth and high yield. The earliest seeding date is dictated by soil temperatures and field conditions such as wetness. Chickpea is a cool-season crop and seedlings are frost tolerant. Chickpea generally germinates when soil temperature is above 40° F (4.4 °C). However, some varieties can tolerate colder temperatures and therefore can be seeded earlier in spring. Seeding can be delayed when the soil is too wet. Late seeding results in shorter plants, late-formed flowers and pods, and lower yield. Flower and pod abortion increase if flowering and pod set coincide with hot, dry weather. More research is needed to determine the relationship between seeding dates and seeding density for different chickpea varieties. With this information, growers will be able to make appropriate decisions on seeding density whenever they are able to seed. The objective of this experiment is to determine the optimum seeding dates and seeding density for two chickpea varieties in the 11-in, 15-in, and 20-in rainfall zones in eastern Oregon.

Methods

To determine the optimum seeding date and seeding density of chickpeas, two *kabuli* varieties, namely 'Dwelley' and 'Sinaloa', were sown at the Sherman Experiment Station in Moro (11-in rainfall), CBARC in Pendleton (15-in rainfall), and at the Nibler Farm (20-in rainfall) in Milton-Freewater in early April, mid-April, and at the end of April. The plants were sown in rows 6 and 12 in apart and at 1.5, 3, and 4.5 seeds/ft^2 (equivalent to 75, 160, and 240 lb/acre, respectively, for 'Dwelley', and 81, 162, and 243 lb/acre, respectively, for 'Sinaloa'). The design was a split, split, split-plot, factorial with seeding dates as main plots, row spacing as subplots, and variety and seeding rates as sub, subplots, completely randomized within subplots.

Chickpeas were grown under conventional tillage methods that differed from site to site. At CBARC and Milton-Freewater, the chickpeas were grown after winter wheat, and after fallow at Moro. Data on plant stand, phenology, grain yield, and grain size were obtained. A plot combine was used to harvest the chickpeas. The peas were graded by passing them through sieves. Chickpeas that did not pass though a 22/64-in sieve were considered "A" grade and those that passed through a 22/64-in sieve but not go through the 18/64-in sieve were considered "B" grade.

Results and Discussion

In general, highest grain yields were obtained in Milton-Freewater, followed by Moro, and the lowest yields were produced in Pendleton. It appears that water was a limiting factor in yield determination. Although the chickpeas in Milton-Freewater and in Pendleton were planted after wheat, there was more rainfall at the former site compared to the latter site. Chickpeas at Moro were grown after fallow using two seasons' rainfall, resulting in more total moisture (stored + growing season) than at Pendleton in 2002. Results and discussion will be limited to treatments that significantly influenced grain yields.

Milton-Freewater

Chickpea grain yield in Milton-Freewater was significantly influenced by planting date, seeding rates, and by an interaction between planting date and variety. Row spacing had no significant effect on grain yield.

Seeding Date Effects on Grain Yield
On average grain yield was highest when planting was done on April 3 (Fig. 1). Delaying seeding to April 17 and May 2 reduced yield by 123 and 139 lb/acre, respectively (Fig. 1).

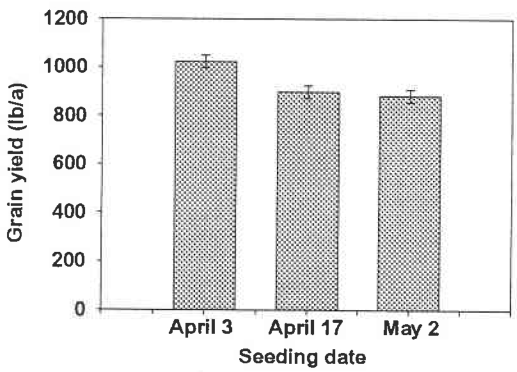

Figure 1. Seeding date effects on chickpea grain yield at the Nibler Farm, Milton-Freewater, Oregon, 2002.

Plants that were sown on April 3 were attacked by a combination of fungi and viruses more than those planted in mid-April and early May. Fungi isolated in Dr. Smiley's lab (CBARC, Pendleton) included *Fusarium solani* and *F. oxysporum*. Viruses isolated from the plants in Dr. Larsen's lab (USDA-ARS, Prosser, WA) included the bean leafroll and alfalfa mosaic viruses. *F. solani* causes cortical root rot resulting in dark lesions and ultimately sunken areas of the root. This root rot damages plants slowly, causing them to become unthrifty and chlorotic but generally not killing them directly. Fusarium root rot can be easily seen by digging or pulling plants in most fields. *F. oxysporum* is a pathogen that causes vascular discoloration and rapid wilting of entire plants. The vascular symptom can only be observed by slicing roots diagonally and looking for discoloration of vascular tissue; the center of the root, or the cortical or epidermal tissues may not necessarily be discolored. The wilt caused early stunting of plants that were randomly scattered through the field. Affected plants became very yellow while still small in June, and they died by July. Despite the disease incidence, the April 3 planting still produced the highest grain yield. This is probably because there was more water available for plants seeded early in April than those seeded later. Plants seeded after the first week of April probably experienced both water and disease stresses.

Seeding Date and Variety Effects on Grain Yield
When sown on April 3, 'Dwelley' produced about 192 lb/acre more grain than 'Sinaloa' (Fig. 2). The varieties, however, produced similar yields at subsequent seeding dates (Fig. 2). At present it is not clear why 'Sinaloa' yielded less than 'Dwelley' when planted on April 3. In general, 'Sinaloa' was significantly shorter than 'Dwelley' and was 5 in shorter when planted in early April and about 2 in shorter when planted in mid-April and early May. This probably resulted in more harvest losses in 'Sinaloa' than in 'Dwelley' in the early seeded plants. Disease incidences were the same in both varieties when planted in early April (data not shown).

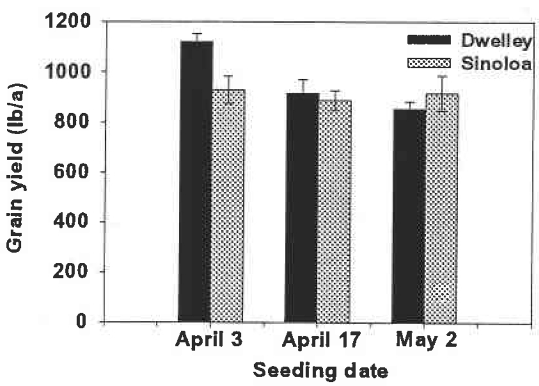

Figure 2. Seeding date and variety effects on chickpea grain yield at the Nibler Farm, Milton-Freewater, Oregon, 2002.

Seeding Date and Variety Effects on Grain Size

'Dwelley' and 'Sinaloa' produced more than 80 percent grade A seed when seeded in the first week of April (Fig. 3a,b). The percentage of grade A peas decreased significantly when 'Dwelley' was seeded after the first week of April (Fig. 3a). The opposite was true for grade B peas. Delaying the seeding of 'Sinaloa' from the first of April to mid-April, however, did not affect the percentage of grade A peas (Fig. 3b). Grain size of 'Sinaloa' decreased when seeding was delayed to the last week of April but the percentage of grade A peas did not decrease below 80 percent (Fig. 3b). Available soil moisture decreased with delay in seeding. The ability of 'Sinaloa' to produce a high percentage of grade A peas when seeded late, therefore, may indicate that 'Sinaloa' is better adapted to limited soil moisture conditions than is 'Dwelley'.

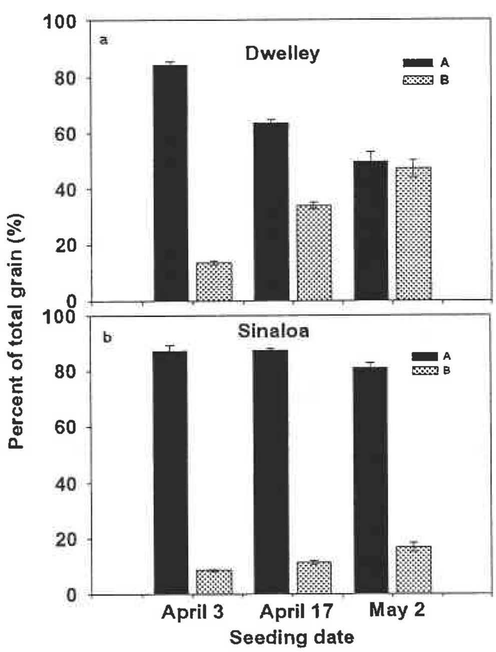

Figure. 3. Seeding date effects on grain size of (a) 'Dwelley' and (b) 'Sinaloa' at the Nibler's Farm, Milton-Freewater, Oregon, 2002.

Seeding Rate Effects on Grain Yield

Grain yield was positively correlated with seeding rates (r = 0.44) and increased when the seeding rates increased from 1.5 to 3 seeds/ft^2 (Fig. 4). Increasing seeding rates from 3 to 4.5 seeds/ft^2 did not result in further increases in grain yield (Fig. 4). Increasing the seeding rate increased the number of plants/ft^2 (r = 0.62).

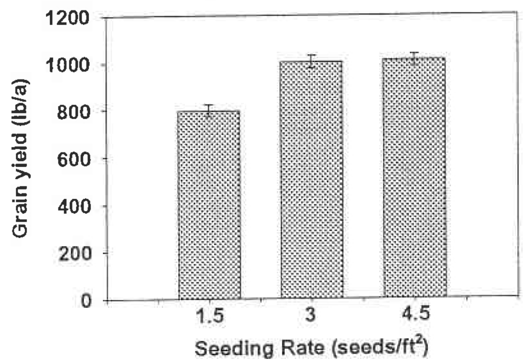

Figure 4. Seeding rate effects on chickpea grain yields at the Nibler Farm, Milton-Freewater, Oregon, 2002.

Pendleton

Chickpea grain yield at CBARC was significantly affected by planting date and interactions between planting date and variety, and seeding rate and variety. Row spacing had no significant effect on yield. Diseases that were observed at the Nibler Farm were also observed in Pendleton. Although plants seeded in early April were most affected by the disease, they produced the highest grain yields.

Seeding Date Effects on Grain Yield

As in Milton-Freewater, the highest grain yield was obtained when chickpeas were seeded in early April (Fig. 5). Delaying seeding to mid-April and late April significantly decreased grain yields by 60 and 156 lb/acre, respectively. This was probably related to rainfall received from planting to harvest (r = 0.42). The crop received 3.76, 2.84, and 2.64 in of rain when planted on April 2, 16, and 30, respectively.

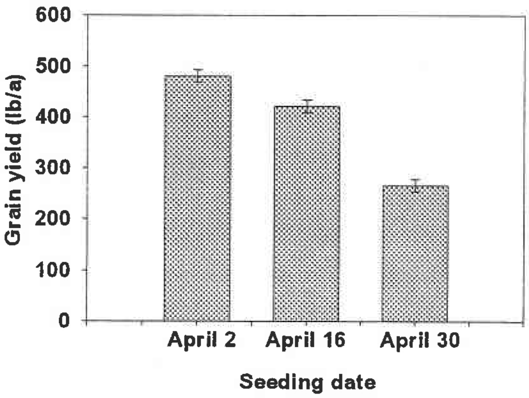

Figure 5. Seeding date effects on chickpea yields at CBARC in Pendleton, Oregon, 2002.

Seeding Date and Variety Effects on Grain Yield

In contrast to Milton-Freewater, 'Sinaloa' at Pendleton produced significantly higher grain yields than 'Dwelley' for all planting dates (Fig. 6). The differences in grain yield were 162, 109, and 318 lb/acre for April 2, 16, and 30, respectively. Given that Pendleton receives less precipitation than Milton-Freewater, it appears that 'Sinaloa' is more drought tolerant than 'Dwelley'.

Seeding Date and Variety Effects on Grain Size

'Dwelley' and 'Sinaloa' produced about 70 and 90 percent grade A seed, respectively, when seeded in the first week of April (Fig. 7a, b). Delayed seeding significantly decreased the amount of grade A seed in both varieties. The decrease in the amount of grade A seed was, however, much greater for 'Dwelley' than for 'Sinaloa' (Fig. 7a, b). The percentage of grade A seed decreased significantly to 25 and 60 when seeding of 'Dwelley' and 'Sinaloa', respectively, was delayed to the end of April (Fig. 7a, b). Given that less soil water was available at Pendleton, this result supports the conclusion that 'Sinaloa' is better adapted to limited soil moisture conditions than 'Dwelley'.

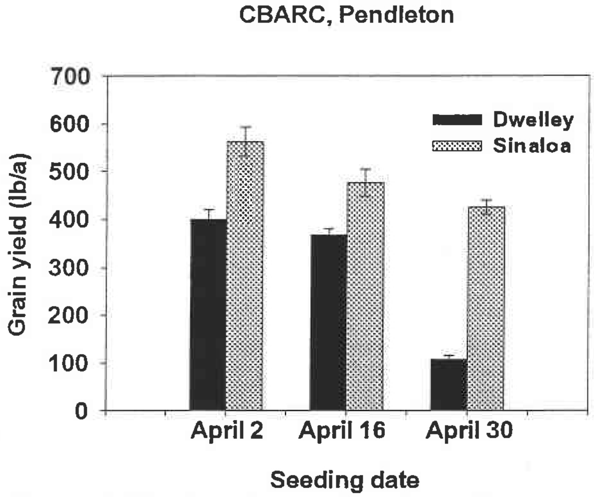

Figure 6. Seeding date and variety effects on chickpea grain yield at CBARC, Pendleton, Oregon, 2002.

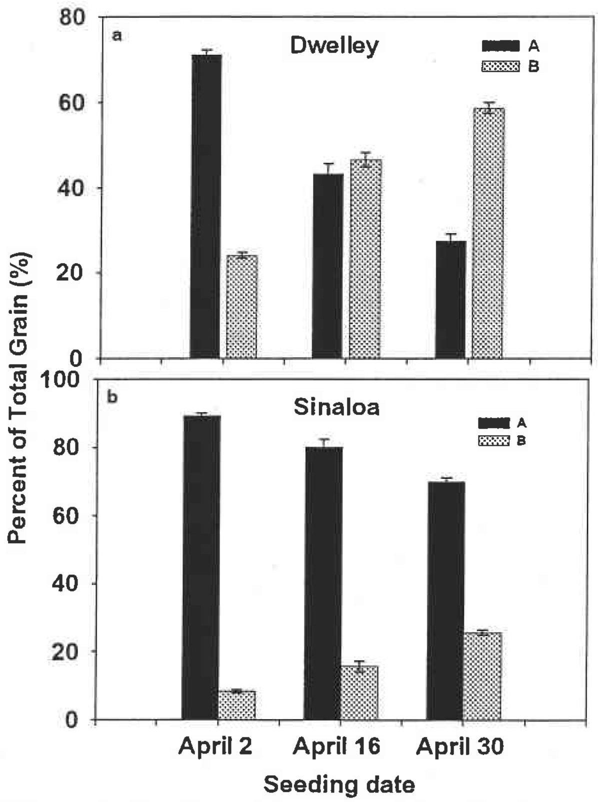

Figure 7. Seeding date and variety effects on grain size of (a) 'Dwelley' and (b) 'Sinaloa' at CBARC, Pendleton, Oregon, 2002.

Seeding Rate and Variety
Increasing seeding rates from 1.5 to 4.5 seeds/ft^2 slightly increased grain yield of 'Dwelley' but significantly increased the yield of 'Sinaloa' (Fig. 8). This suggests that 'Sinaloa' can tolerate crowded conditions even under the low moisture conditions experienced at this site.

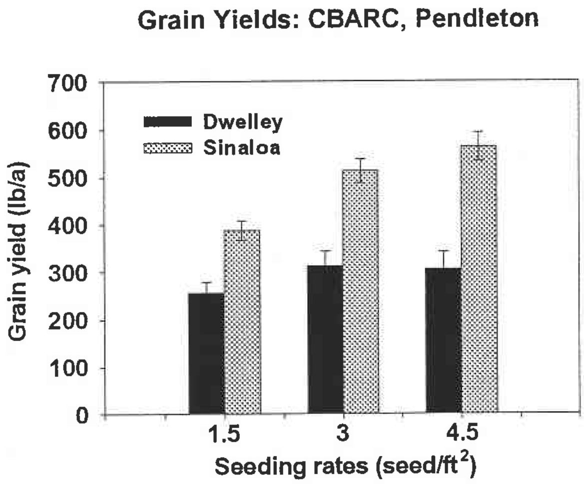

Figure 8. Seeding rate and variety effects on chickpea grain yield at CBARC, Pendleton, Oregon, 2002.

Moro
Grain yield at the Sherman Experiment Station in Moro was influenced by interactions between planting date and variety and seeding rate and variety. Row spacing had no significant effect on grain yield. Diseases that were observed at the Nibler Farm and in Pendleton were also observed in Moro. Although plants planted in early April were most affected, they produced the highest grain yields.

Seeding Date Effect on Grain Yield
Like at the other sites, chickpea grain yield was highest with seeding in early April and decreased on subsequent seeding dates (Fig. 9). Grain yield appears to be influenced by the amount of rainfall received after planting (r = 0.59). The crop planted on April 1, 15, and 29 received 1.93, 1.56, and 1.55 in of rain, respectively.

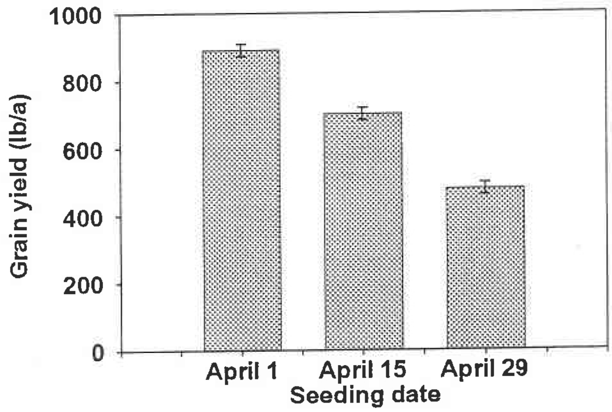

Figure 9. Seeding date effects on chickpea grain yield at the Sherman Experiment Station, Moro, Oregon, 2002.

Seeding Date and Variety Effects on Grain Yield
'Sinaloa' produced significantly higher grain yields than 'Dwelley' at all planting dates (Fig. 10). The yields were higher by 141.33, 148.94, and 230.61 lb/acre when the varieties were planted on April 1, 15, and 29, respectively. These results indicate that 'Sinaloa' is better adapted to the limited rainfall conditions in Moro.

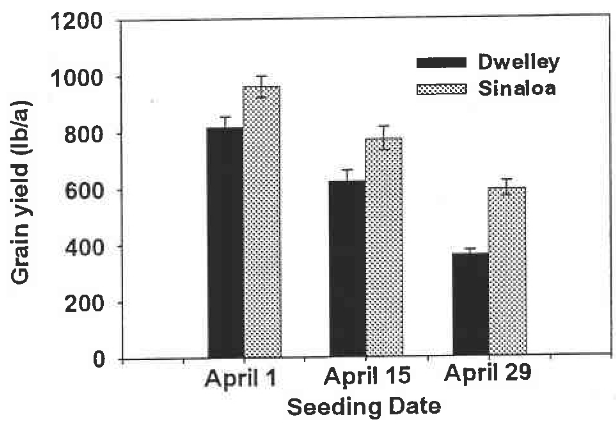

Figure 10. Seeding date and variety effects on chickpea grain yield at the Sherman Experiment Station, Moro, Oregon, 2002.

Seeding Date and Variety Effects on Grain Size
At Moro, grain size was not affected by planting date in either variety (Fig. 11a, b). However, more than 80 percent of grain from 'Sinaloa' was A grade compared to about 60 percent from 'Dwelley' (Fig. 11a, b). This result further confirms that 'Sinaloa' consistently produces bigger grain than 'Dwelley' in different environments.

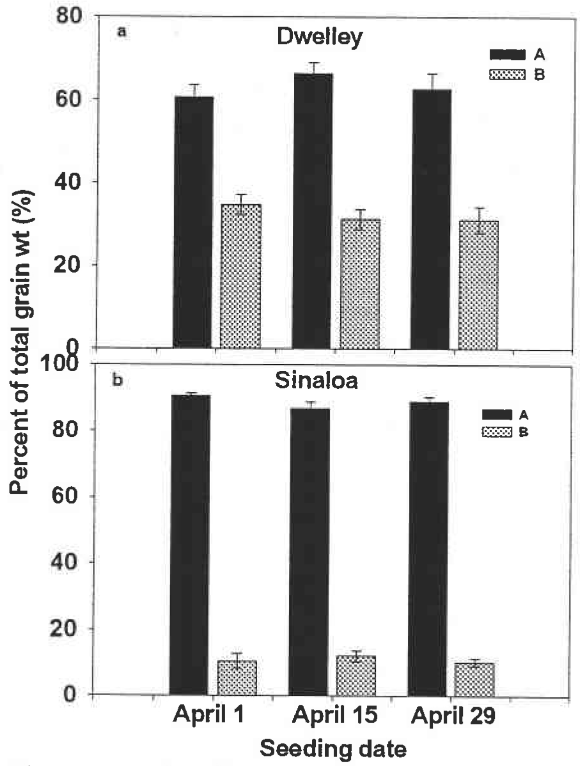

Figure 11. Seeding date and variety effects on grain size of (a) 'Dwelley' and (b) 'Sinaloa' at the Sherman Experiment Station, Moro, Oregon, 2002.

Seeding Rates and Variety Effects on Grain Yield
Like at Pendleton, the grain yield of 'Sinaloa' significantly increased with increasing seeding rates (Fig. 12). The yield of 'Dwelley' significantly increased when the seeding rate was increased from 1.5 to 3 seeds/ft^2 but did not respond to a further increase in seeding rate. At each seeding rate, the yield of 'Sinaloa' was significantly higher than that of 'Dwelley'. This suggests that 'Sinaloa' is better suited to the low moisture conditions experienced in Moro than 'Dwelley', even under high plant densities.

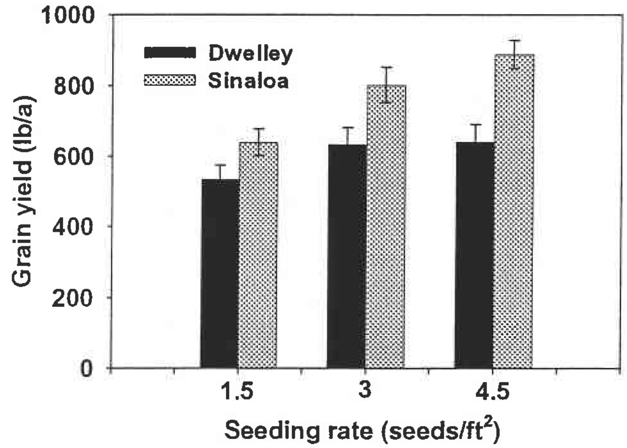

Figure 12. Seeding rate and variety effects on chickpea grain yield at the Sherman Experiment Station, Moro, Oregon, 2002.

Conclusions

Based on the preliminary results, we recommend to plant early in April in areas with similar climatic conditions to the sites used in this study. 'Dwelley' appears to be the variety of choice in high rainfall areas and 'Sinaloa' for low rainfall areas. The grain size of 'Dwelley' decreased when planting was delayed from the first week of April but that of 'Sinaloa' was not affected as much. The optimum seeding rates for 'Dwelley' is 3 seeds/ft^2 and that of 'Sinaloa' is 4.5 seeds/ft^2 although this high seeding rate may not be economical. Both varieties can be planted at either 6- or 12-in-row spacing. The experiment will be repeated in the spring of 2003.

Acknowledgements

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USDA-ARS CLUB WHEAT BREEDING IN OREGON

Kimberly Garland Campbell, Nathan Blake, and Lynn Little

Abstract

Club wheat was planted on 36,000 acres in Oregon for 2002. Club wheat is mixed with soft white wheat resulting in a mixture called Western White. Western White is sold to Japan and neighboring countries and is used in sponge cakes and other pastries.

The objective of this research was to evaluate winter club breeding lines at diverse Oregon locations with the goal of developing high quality, competitive winter club cultivars suited to northeastern Oregon growing conditions.

Breeding lines were evaluated at four Oregon sites and one southeastern Washington site for yield, test weight, plant height, heading date, and quality; crosses and seed increases were done in the greenhouse. Coleoptile length and leaf breadth measurements were taken. Two new cultivars ('Chukar', club and 'Finch', common) have been released by the USDA-ARS in Pullman, Washington with the help of Columbia Basin Agricultural Research Center scientists and Oregon cooperators.

Key words

Triticum aestivum, Triticum compactum, 'Finch', 'Chukar', wheat breeding

Introduction

The USDA-ARS Wheat Breeding Program is located in Pullman, Washington at the USDA-ARS Wheat Genetics, Quality, Physiology, and Disease Research Unit. Kimberly Garland Campbell is head of the Wheat Breeding/Genetics Program and the Western Regional Cooperative Nurseries. The Oregon sites are managed by Nathan Blake.

Materials and Methods

Four northeastern Oregon sites (Hermiston, Lexington, Moro, and Pendleton) and one southeastern Washington site (Walla Walla) were used for 17 breeding and 3 Western Regional nurseries. All sites were non-irrigated except Hermiston. The Pendleton and Moro nurseries were located at the Columbia Basin Agricultural Research Center (CBARC) and the Sherman Experiment Station. The other two Oregon sites were on Kent Madison's farm near Hermiston and Starvation Farms (Chris Rauch cooperator) near Lexington. The Walla Walla nurseries were located on Guy McCaw's farm. Over 250 late breeding lines and 430 early generation lines were evaluated in yield trials in Oregon for 2002.

Pendleton

Winter wheat nurseries were seeded October 4, 2000 at the CBARC. Nurseries evaluated at CBARC included the USDA-ARS Elite, Advanced, and Tall, and comprised a total of 36 entries replicated 3 times. Purification Yield trials 1, 2, 3, and 4 included 36 non-replicated entries. All breeding nurseries were planted using a partially balanced lattice design with three replications. Two cooperative regional nurseries, the Western Regional Soft Winter Wheat Nursery and the Western Regional Hard Winter Wheat Nursery, were planted using a randomized complete block design with three replications. The USDA-ARS Winter Wheat Quality Evaluation nursery was planted as a randomized complete block including 71 entries with two replications. All seed was treated prior to planting with Raxil-Thiram® (Gustafson) and Gaucho® (Bayer) at recommended label rates. Seeding rate was approximately 20 seeds per ft^2. Anhydrous ammonia was incorporated into conventional fallow before planting to increase the nitrogen amount to 216 lb/acre. This is based on 2.7 lb N/acre/bu multiplied by 80 bu/acre estimated yield. No fertilizer was applied in the spring. Plots were seeded approximately 2 in deep using a Hege five-row hoe-opener plot drill. Plot size was approximately 82.5 ft^2. Moisture was adequate at planting and emergence was good. Spring stands of some plots were damaged by gophers. Hoelon® (Bayer) was applied at 2.67 pints/acre to control downey brome. Spring weed control was obtained by spraying plots with Bronate® (Bayer) (2pt/acre) on April 8.

Plots were evaluated for spring stand (percentage), heading date, height, spike morphology, harvested plot length, grain yield, and test weight. Heading date was noted as days from January 1 until 50 percent of the plot had headed. Height was measured on an outside row of the plot from the ground to the bottom of the spikes. Disease notes were not taken at Pendleton because diseases were few. Plots were harvested on July 16, 2002 using a Hege small plot combine. Harvested plot length was determined just prior to harvest. Grain yield and test weight were determined on grain samples that had been cleaned using a small-sample Hege cleaner. A 400 g sample was saved from each plot and sent to the Western Wheat Quality Laboratory in Pullman Washington for evaluation. Quality data are not available at this time.

Hermiston

The USDA-ARS Elite replicated yield trial was planted at Hermiston on October 17, 2001 using the same experimental design as at CBARC. Seeding was done using a drill with accu-plant® double-disk openers at approximately 20 seeds per ft^2. Planting depth was approximately 1 in deep. Moisture was good and emergence was good. Fertility and weed control were managed by the cooperator. Experimental design and data collected were as described above. Plots were harvested on July 19, 2001. Grain yield and test weight were determined as described for CBARC.

Lexington

The USDA-ARS Elite replicated yield trial was planted at Lexington on November 5, 2001 using the same experimental design as at CBARC. Seeding was done using a Hege five-row hoe-opener planter at approximately 16 seeds per ft^2. Planting depth was approximately 1 in deep. Moisture was adequate and emergence was good. Fertility and weed control were managed by the cooperator. Experimental design and data collected were as described for CBARC. Plots were harvested on July 12, 2002. Grain yield and test weight were determined as described above.

Moro

Nurseries evaluated at the Sherman Experiment Station included the USDA-ARS Elite, Advanced, Tall, and the two cooperative regional nurseries (Western Regional Soft Winter Wheat Nursery and Western Regional Hard Winter Wheat Nursery). Nitrogen fertility included 72 lb/acre residual N in the top 4 ft of the soil profile and an application of 40 lb N/acre of anhydrous ammonia increasing the total N to 112 lb/acre. Plots were seeded on October 10, 2000 at approximately 16 seeds per ft^2. Planting depth was approximately 1.5 in deep. Moisture was good and emergence was good. Experimental design and data collected were as described for CBARC. Plots were harvested on July 17, 2002. Grain yield and test weight were determined as described above.

Disease Assessment

Evaluation of resistance to strawbreaker foot rot (caused by *Tapesia yallundae* Wallwork & Spooner = *Pseudocercosporella herpotrichoides* [Fron] Deighton), Cephalopsorium stripe (caused by *Hymenula cerealis* Ellis & Everh.), and stripe rust (caused by *Puccinia striiformis* Westend. f. sp. *tritici*) was conducted at the Washington State University (WSU) Spillman Agricultural Research Farm. Plots were single-row plots, 3 ft long 12 in apart, set in a RCB with three replications. Appropriate resistant and susceptible checks were included after every eight plots in disease nurseries. The Cephalosporium stripe nursery was planted on September 20, 2000; the strawbreaker foot rot nursery on September 19, 2000; and the stripe rust nursery on October 30, 2000. The Cephalosporium stripe nursery was inoculated by spreading *H. cerealis*-infested oat kernels on plots on October 10, 2000. The strawbreaker foot rot nursery was inoculated on November 15, 2000 with a spore suspension derived from a *T. yallundae* isolate obtained from Tim Murray (WSU). The stripe rust nursery was inoculated in April and May of 2001 by spreading a mixture of rust spores and talcum powder on plots using a hand-held dust applicator. Spores were generated from stripe rust isolates PST-17, PST-37, PST-43, and PST-45 (virulent on 'Twin', 'Stephens', 'Tres', and 'Hyak', respectively). Disease rating in the cephalosporium stripe and strawbreaker foot rot nurseries was evaluated on a one-to-five scale with five matching symptoms of the susceptible check and zero indicating absence of disease symptoms. Disease rating in the stripe rust nursery was based on infection type and percent leaf area infected.

Crossing Program

In the winter of 2001, winter and spring breeding lines were crossed with sources of adult plant stripe and leaf rust resistance obtained from Ravi Singh at the International Maize and Wheat Improvement Center (CIMMYT). During winter of 2002 the F1 lines were backcrossed and crossed with other lines. Seed increases of 88 spelt lines obtained from the National Small Grains Germplasm Collection also were done. These accessions are being evaluated in disease nurseries in Pullman Washington beginning in the fall of 2001. Crosses were also done with Chuck Rohde's elite lines.

Coleoptile Testing

Coleoptile length of breeding lines from the USDA-ARS program was evaluated as described in Hakizimana et al. 2000. Ten seeds were placed 1 cm apart with the germ down and 3 cm from the bottom of a wet germination towel. The towels were folded over, rolled loosely, and placed upright in plastic trays. The samples were placed in a dark incubator at 4°C for 4 days. After 4 days the samples were removed and placed in another dark incubator at 15°C for 16 days. The samples were measured to the nearest mm using a clear ruler. The goal is to identify genotypes with long coleoptiles that will emerge readily from deep planting.

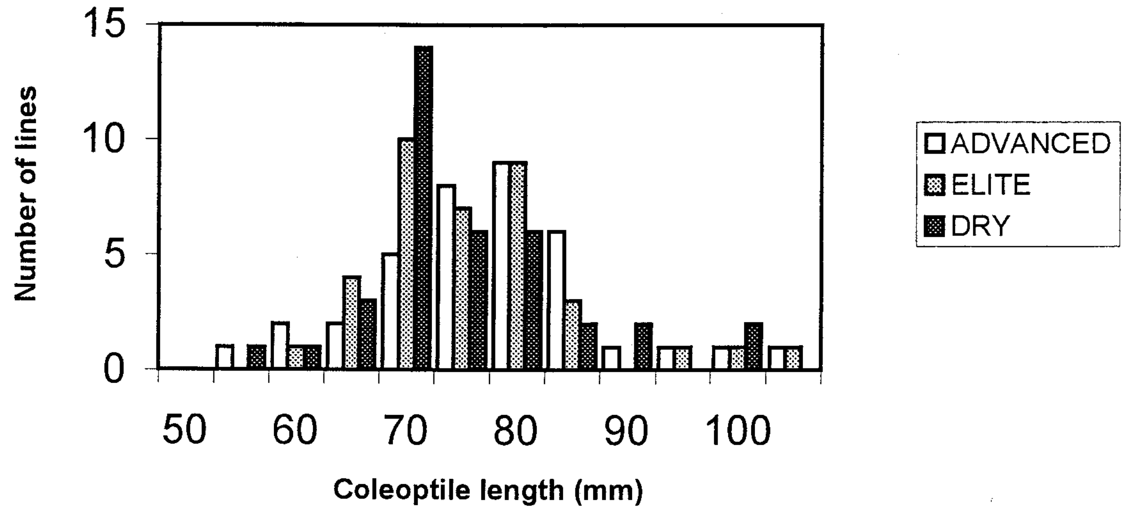

Figure 1. Coleoptile lengths for breeding lines in USDA-ARS Wheat Breeding program

The lines with the longest coleoptile length (four lines from 95 to 100 mm long) were the checks 'Moro' and 'Edwin'. Several breeding lines have coleoptile lengths above 80 mm. In the Dry nursery, most of the lines with coleoptile lengths below 60 mm were eliminated. For comparison, 'Hiller' and 'Madsen' had lengths of 65 mm while 'Eltan' and 'Finch' had lengths of 75 mm.

Leaf Breadth Testing

Leaf breadth of breeding lines from the USDA-ARS program is being evaluated at CBARC as described in Richards et al. 2002. Seed was germinated and put in a growth chamber at 22°C for 10 days. The first two leaves were measured to the hundredth mm at the widest point using a digital micrometer. The goal is selecting for genotypes that compete better with weeds and use water and sunlight more efficiently through more rapid canopy closure.

Results

Two New Cultivars Were Released

'Chukar' winter club wheat (*Triticum aestivum* L.) was developed by the USDA-ARS with assistance from the Washington Agricultural Experiment Station and the Oregon Agricultural Experiment Station. It was released in September of 2001 with a combination of high yield potential, disease resistance, and the desirable quality characteristics for the club wheat market class. Yields of 'Chukar' have been equal to or up to 5 percent better than those of 'Coda' club wheat and 'Madsen' soft white winter wheat for over 5 years of multi-location yield trials in the Pacific Northwest.

The test weight of 'Chukar' has been good. 'Chukar' is best suited to the intermediate to high rainfall zones of Washington and north Idaho. It is resistant to strawbreaker foot rot and carries the *Pch1* gene for resistance, derived from Roazon. 'Chukar' is resistant to stripe rust, moderately resistant to powdery mildew, moderately susceptible to leaf rust, and susceptible to dwarf bunt. The end-use quality of 'Chukar' is excellent as compared with other club wheat varieties. 'Chukar' is an alternative to the club wheat 'Hiller' in intermediate to high rainfall environments when foot rot is a problem. It has exhibited consistent and stable yields, most likely because it possesses resistance to multiple diseases.

'Finch' soft white winter wheat (*Triticum aestivum* L.) was developed by the USDA-ARS with assistance from the Washington Agricultural Experiment Station and the Oregon Agricultural Experiment Station. It was released in February 2001 with a combination of high yield potential, disease resistance, and excellent end-use quality characteristics for soft white wheat in the Pacific Northwest. 'Finch' is resistant to strawbreaker foot rot and carries the *Pch1* gene for resistance derived from *Aegilops ventricosa* Tausch. 'Finch' is moderately resistant to stripe rust and to powdery mildew, has a low level of resistance to Cephalosporium stripe and to leaf rust, and is susceptible to Hessian fly (*Mayetiola destructor* [Say] *Phytophaga destructor* [Say]) and snow mold (*Typhula idahoensis* Remsberg *T. incarnata* F) based on its pedigree. 'Finch' is an alternative to 'Madsen' with a 5 percent yield advantage, slightly better emergence, more consistent yields in low and intermediate rainfall zones, better test weight, and significantly better end-use quality. 'Finch' is best suited to the low to intermediate rainfall zones of Washington, Oregon, and north Idaho.

The relatively late maturity of 'Finch' and 'Chukar' compared to 'Stephens' may limit their adaptability in northeast Oregon. Both have performed well in yield trials conducted in Oregon from 2000 to 2002. Yield trial results are from the Elite and Advanced nurseries (Tables 1 and 2)

Table 1. USDA-ARS club wheat breeding Elite Nursery agronomic data at Oregon locations, 2002.

Name	Heading (after Jan. 1)				Height (cm)					Test weight (lb/bu)					Yield (bu/acre)				
	Herm	Moro	Pend	Mean	Herm	Lex	Moro	Pend	Mean	Herm	Lex	Moro	Pend	Mean	Herm	Lex	Moro	Pend	Mean
A00103	141	150	152	148	102	48	56	81	72	56.1	56.3	53.8	55.1	55.3	124.8	24.7	51.4	82.3	70.8
A00127	140	151	152	148	117	48	53	91	77	60.3	57.2	55.0	58.1	57.6	125.8	22.2	46.2	79.1	68.3
A00143	131	151	151	144	109	51	53	84	74	58.8	58.3	56.1	58.9	58.0	114.4	20.7	39.8	79.5	63.6
A00150	137	149	146	144	109	53	53	81	74	61.8	57.7	57.9	60.2	59.4	119.0	20.3	42.2	78.6	65.0
A00173	133	151	154	146	102	56	66	86	77	58.0	55.7	52.8	57.9	56.1	123.0	22.5	33.4	83.7	65.7
A00181	141	151	153	148	112	53	56	89	77	59.9	57.6	54.5	59.3	57.8	117.4	22.7	36.2	74.0	62.6
A00187	139	151	151	147	102	51	61	84	74	58.8	57.6	54.1	56.8	56.8	108.1	24.7	35.4	76.0	61.1
A00226	142	150	152	148	119	51	64	94	82	56.7	55.4	53.5	56.5	55.5	100.3	24.3	45.0	78.6	62.1
A00235	143	151	155	150	112	48	64	86	77	58.5	55.6	55.5	60.0	57.4	112.4	22.0	45.0	83.3	65.7
A96158	140	151	154	148	99	51	51	84	71	56.6	55.3	52.3	53.8	54.5	119.4	21.4	39.8	72.4	63.2
A97134-1	132	152	152	145	102	46	51	81	70	58.6	57.6	53.8	58.2	57.0	125.1	23.1	38.8	70.9	64.5
A97135-9	142	152	150	148	107	43	51	81	70	56.7	53.7	53.8	55.8	55.0	119.9	21.4	44.2	80.5	66.5
A97173-16	140	151	148	146	107	43	53	91	74	58.1	57.4	55.6	59.0	57.5	127.0	23.6	42.4	87.0	70.0
A98143	140	150	155	148	112	48	66	86	78	58.6	56.8	55.3	57.7	57.1	116.5	22.3	41.3	73.3	63.4
A99105	138	150	147	145	97	51	64	79	72	58.1	57.0	57.5	57.7	57.6	122.5	25.8	47.9	84.1	70.1
A99138	133	151	154	146	97	46	56	86	71	57.5	54.7	55.2	55.9	55.8	113.0	20.9	42.6	76.7	63.3
A99165	140	151	151	147	109	56	69	79	78	61.2	58.6	57.7	60.0	59.4	125.6	22.8	38.0	78.7	66.3
A99236	139	150	152	147	104	51	61	81	74	59.4	57.3	56.4	56.8	57.4	121.7	20.2	42.2	67.3	62.8
ARS96105	143	153	154	150	104	58	69	86	79	53.9	55.4	56.4	57.5	55.8	106.0	24.6	40.0	68.9	59.9
ARS96277-37	129	149	147	142	91	58	71	79	75	62.1	58.9	57.7	59.5	59.5	124.3	28.3	45.0	78.5	69.0
ARS97123-12	142	151	152	148	104	53	53	94	76	57.4	54.4	53.1	56.0	55.2	125.4	23.0	42.1	84.2	68.7
ARS98237-28	131	151	150	144	104	38	64	79	71	58.7	55.1	54.8	56.1	56.2	130.3	25.5	45.8	71.0	68.2
ARS99136	139	148	148	145	112	53	71	91	82	56.5	57.1	53.7	55.7	55.7	112.1	22.1	39.7	72.6	61.6
ARS99137	141	151	154	149	94	46	48	94	70	57.7	54.6	54.1	57.1	55.9	114.8	20.0	38.8	74.2	61.9
Bruehl	143	153	156	151	107	61	58	97	81	53.6	56.7	55.4	54.0	54.9	109.9	24.5	38.4	75.4	62.0
Chukar	143	152	151	149	107	48	53	94	76	56.4	54.6	54.0	54.7	54.9	119.2	21.7	39.4	73.9	63.6
Coda	144	151	155	150	102	56	71	94	81	59.7	56.8	54.5	59.0	57.5	113.7	23.4	39.6	73.1	62.5
Edwin	140	151	153	148	119	61	71	104	89	59.9	57.1	54.9	58.1	57.5	110.3	23.2	40.1	60.1	58.4
Finch	142	152	152	149	102	61	66	94	81	58.7	59.2	59.9	59.3	59.3	120.9	27.1	50.4	82.2	70.1
Hiller	139	151	150	147	102	51	61	91	76	57.3	56.3	53.7	55.8	55.8	127.9	24.0	41.4	81.2	68.6
Lambert	135	147	148	143	104	66	79	102	88	59.2	55.5	54.7	57.9	56.8	112.4	24.7	46.9	89.2	68.3
Madsen	138	152	147	146	94	58	71	91	79	59.7	57.8	56.1	58.6	58.0	121.7	27.8	46.8	78.6	68.7
Rely	141	151	151	148	99	48	66	91	76	56.8	56.6	54.3	58.0	56.4	101.4	23.0	47.1	85.4	64.2
Stephens	135	147	147	143	104	58	61	81	76	60.8	55.9	56.1	56.4	57.3	126.0	26.0	47.0	80.1	69.8
Temple	140	150	148	146	112	53	69	102	84	56.0	57.7	54.7	58.7	56.8	110.6	25.1	41.3	82.4	64.9
Weatherford	139	150	149	146	107	69	61	97	83	59.2	57.6	56.8	56.2	57.5	120.6	28.4	44.4	74.5	67.0

Table 2. USDA-ARS Club wheat breeding Advanced Nursery agronomic data at Oregon locations, 2002.

	Heading (after Jan. 1)			Height (cm)				Test weight (lb/bu)				Yield (bu/acre)			
Name	Moro	Pend	Mean	Moro	Pend	WW	Mean	Moro	Pend	WW	Mean	Moro	Pend	WW	Mean
A00134	151	153	152	66	86	89	80	53.8	54.6	57.8	55.4	36.1	59.7	100.4	65.4
A00140	151	153	152	69	84	94	82	54.3	57.2	59.0	56.8	28.9	58.6	95.9	61.1
A00151	151	154	153	56	91	99	82	57.5	58.5	61.3	59.1	34.1	58.9	110.4	67.8
A00154	151	156	154	61	97	104	87	55.6	58.4	60.3	58.1	29.8	61.7	112.2	67.9
A00202	152	156	154	53	91	97	80	56.0	56.5	58.9	57.1	33.8	64.0	93.4	63.7
A00203	152	154	153	53	89	99	80	54.6	56.6	60.0	57.1	37.6	61.9	100.2	66.6
A00209	152	155	154	66	84	89	80	54.1	56.1	58.4	56.2	32.6	60.0	85.2	59.2
A99123	148	155	152	71	81	79	77	56.6	57.4	60.6	58.2	43.2	65.5	96.1	68.3
Bruehl	153	156	155	71	86	97	85	55.8	53.8	58.0	55.9	37.5	60.3	105.9	67.9
C3950903	152	157	155	64	94	97	85	54.0	57.0	59.0	56.7	27.8	62.4	97.1	62.4
C3950905	152	154	153	58	86	86	77	54.0	57.6	60.4	57.3	30.5	58.0	87.2	58.6
C96068	149	152	151	69	91	112	91	55.2	54.9	59.9	56.7	34.0	63.4	113.1	70.1
Chukar	152	155	154	61	86	91	80	55.1	56.4	58.4	56.6	39.4	68.6	106.4	71.5
Coda	152	155	154	76	91	89	86	56.1	58.8	60.9	58.6	34.5	67.9	111.4	71.3
Finch	152	153	153	79	91	94	88	58.5	58.5	60.9	59.3	37.5	69.8	106.2	71.2
Hiller	151	155	153	71	81	91	81	54.6	55.1	57.0	55.6	43.9	65.9	104.7	71.5
Madsen	150	155	153	79	79	86	81	57.7	57.0	59.9	58.2	42.6	66.2	107.8	72.2
Stephens	146	154	150	81	86	84	84	57.5	54.5	60.1	57.4	48.6	61.4	93.3	67.8
Temple	.	155.		.	81.	.		.	56.1.		56.1	.	60.8.		60.8
X850297	152	154	153	71	91	117	93	55.3	58.0	60.9	58.0	26.0	58.0	89.6	57.9
X950312	152	156	154	69	97	119	95	56.6	58.9	62.0	59.1	32.3	56.5	92.2	60.3
X950317	152	156	154	69	94	102	88	51.7	54.9	57.5	54.7	28.0	66.1	105.9	66.7
X960407	152	156	154	56	84	97	79	55.2	58.5	59.9	57.8	34.9	69.3	103.8	69.3
X960409-1	151	154	153	64	89	91	81	55.2	57.9	60.3	57.8	31.5	62.1	110.0	67.9
X960409-2	153	155	154	58	94	107	86	54.5	57.6	59.3	57.1	34.2	65.9	104.8	68.3
X960411-1	151	155	153	61	91	97	83	56.6	59.5	60.9	59.0	35.2	66.7	106.1	69.3
X960411-2	150	152	151	69	99	97	88	57.8	59.0	60.0	59.0	39.4	71.2	104.6	71.7
X960414-1	151	154	153	64	84	99	82	56.7	60.1	62.0	59.6	35.4	68.1	112.4	72.0
X960414-2	151	154	153	61	76	102	80	57.7	60.0	62.0	59.9	34.7	66.0	116.1	72.3
X960418	152	155	154	66	84	94	81	57.0	59.8	61.2	59.3	35.8	68.9	116.2	73.6
X960433	152	156	154	64	91	89	81	51.6	57.0	59.4	56.0	20.3	61.8	98.2	60.1
X960491	151	154	153	58	86	97	80	56.3	58.0	61.1	58.5	36.3	68.0	110.0	71.4
X960499	152	151	152	58	89	102	83	53.0	56.8	59.2	56.3	30.0	65.3	104.6	66.7
X960527	150	155	153	69	84	99	84	55.0	55.9	57.9	56.3	41.0	69.7	108.5	73.0
X960531	150	155	153	58	86	97	80	54.6	58.1	59.5	57.4	31.5	72.1	102.0	68.6
X960589	150	155	153	56	84	97	79	54.5	55.6	58.7	56.2	38.6	68.9	101.6	69.7

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GENETIC TOLERANCE TO FUSARIUM CROWN ROT OF WHEAT

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Abstract

Fusarium pseudograminearum is one of the pathogenic fungi that cause Fusarium crown rot (dryland foot rot) of winter and spring wheat. Winter wheat varieties and breeding lines were evaluated for 3 years in inoculated or non-inoculated paired plots at Pendleton and Moro, Oregon. Five pathogen isolates on millet-seed substrate were mixed and dispensed 1in above wheat seed at planting. Wheat seed treated with benomyl to suppress Fusarium damping-off was planted with a John Deere HZ drill equipped with cone-seeder on 14-inch row spacing. Plant stand, disease incidence and severity, and grain yield, test weight, and kernel weights were measured. Inoculation reduced average winter wheat yield at Pendleton by 12, 12, and 61 percent during 1999-2000, 2000-2001, and 2001-2002, respectively. Inoculation reduced winter wheat yield at Moro by 50 percent during 2001-2002. Commercial winter wheat varieties were ranked according to genetic tolerance; e.g., ability to produce grain yield even when infected by the pathogen. No varieties or breeding lines were considered resistant, e.g., ability to prevent infection by the pathogen. Spring wheat varieties and breeding lines were also tested at Moro during 2002. Six Australian varieties representing a range of plant tolerance ratings in that country were tested in four experiments in Oregon during 2000-2002. Performance of these varieties was comparable in Oregon and in Australia. Several Australian and Pacific Northwest wheat lines have levels of tolerance worthy of additional examination in wheat breeding programs.

Key Words

Fusarium pseudograminearum, genetic resistance, genetic tolerance, spring wheat, winter wheat

Introduction

Fusarium is a diverse genus of fungi that includes several soilborne plant pathogens. Fungi in several other genera cause similar damage and often are present as a pathogen complex with *Fusarium* species. These pathogens damage small-grain cereals by rotting seed, seedlings, roots, crowns, basal stems or heads of wheat, barley, oats, corn, grasses, and some broadleaf crops. Damage to spring and winter cereals is often unnoticed until whiteheads appear shortly before the crops mature or until shriveled grain is noted during harvest. Damage can be highly variable within fields. Yield reductions in commercial winter wheat fields have been as high as 35 percent.

The fungi included in this pathogen complex occur in different proportions in each geographic region. The prevalence of each species varies in response to annual climate cycles as well as more static differences among regions. The disease complex is therefore dominated by different pathogens in different areas, and even by different pathogens during successive growing seasons on individual fields. The dominant pathogen region-wide is *F. pseudograminearum*. Other important members of the pathogen complex in the Pacific Northwest include *F. culmorum* and *Bipolaris sorokiniana*. These pathogens cause chronic infections. Infected plants are often able to produce normal yields if they are not exposed to stressful environmental conditions during the growing season. Yield reductions become apparent when infected plants are subjected to water stress and/or hot temperature late in the growing season. It is ironic that the most widespread pathogen, *F. pseudograminearum,* is also well adapted for causing extensive damage in regions of high rainfall and in irrigated fields. These pathogens have therefore evolved to maintain their populations under diverse climatic conditions and management practices.

Diseases caused by these fungi are known by a variety of names, including Fusarium crown rot, dryland foot rot, Fusarium foot rot, dryland root rot, Fusarium root rot, and common root rot. We use the name Fusarium crown rot in this report. In winter wheat/summer fallow rotation, damage by Fusarium crown rot is favored by applying all nitrogen fertilizer into soil before planting, and by planting while the soil is still warm. The disease becomes most damaging in high-residue cropping systems and short rotations, which are conditions particularly applicable to annual-cropped spring cereals.

Management of damage by Fusarium crown rot has been heavily dependent on practices that conflict with preferred agronomic or economic considerations and with uncontrollable events related to weather. Management practices that minimize disease severity for winter wheat include tilling soil to minimize surface residue, planting when the seed-zone soil temperature is below 50°F, and reducing late-season water stress by planting with wide-row spacing and/or low seeding rate, and by splitting fertilizer applications to minimize the amount of nitrogen available to seedlings. Most of these management practices are contrary to practices known to produce highest grain yields when crops are not heavily infected by *Fusarium* and/or *Bipolaris* species. It is therefore recognized that control of Fusarium crown rot will only be achieved by crop management systems that include varieties with disease tolerance or resistance.

Genetic tolerance describes the ability of a plant to produce acceptable yield even when that plant is infected by the pathogen. Tolerance does not necessarily limit the ability of the fungus to infect or damage tissue, and it does not necessarily lead to a reduction in numbers of reproductive spores produced by the fungus on infected plants. Tolerance simply allows a plant to withstand the infection. It does not reduce the risk to future crops, and it may fail to adequately protect plants when climatic conditions and crop management are highly favorable for disease development. Tolerance is evaluated by comparing yields from plants grown under field conditions in soils highly or only lightly infested by the pathogen(s). Plants can be tolerant without being resistant to the disease.

Genetic resistance describes the ability of a plant to retard or prevent infection by the pathogen. Resistant plants sustain very little damage to their tissue. Resistant plants also reduce spore production by the pathogen, and therefore reduce the potential risk to future crops. Resistance is likely to be more effective than tolerance when conditions are highly favorable to disease. Resistance can be measured by evaluating the presence or absence of infection, or relative severity of infection, in either seedlings or in plants grown in the field.

The objectives of this study were to (1) determine whether tolerance or resistance was present among winter and spring wheat varieties and breeding lines in the Pacific Northwest, (2) describe the stability of tolerance over time if tolerance was detected, and (3) examine the tolerance in Oregon of wheat varieties used as standards for comparison in Fusarium crown rot breeding programs in Australia.

Methods

Winter Wheat Varieties

The relationship of Fusarium crown rot to growth and yield of 18 winter wheat varieties and advanced breeding lines was evaluated for 3 years at the Columbia Basin Agricultural Research Center. Long-term (20-yr) mean annual precipitation is 17.9 and 11.5 inch for stations at Pendleton and Moro, respectively. Soils are Walla Walla silt loams naturally infested with the pathogen. Trials were planted into different fields each year. All fields were maintained as cultivated summer fallow for 14 months following harvests of lentil (1999-2000 trial) or winter wheat (other trials). Seeds were treated with benomyl (Benlate 50W, at 0.75 oz/cwt) and planted at 23-25 seed/ft^2 into 5- x 20-ft plots with a John Deere HZ deep-furrow drill equipped with a cone seeder and four openers spaced at 14 inches.

Seed was planted with and without supplemental inoculum consisting of five isolates of *F. pseudograminearum* from infected wheat crowns. Inoculum was placed in two of the four rows of each drill pass. Inoculum was grown on autoclaved millet seed. Individual isolates were mixed in equal proportions prior to use. Inoculum was dispensed at about 140 millet seed/ft from a Gandy spreader on the seed drill, and was placed 1-inch above the crop seed to force coleoptiles to emerge through the band of inoculum.

Wheat at Pendleton was planted on 24 September 1999, 22 September 2000, and 18 September 2001. Planting depth was 3-inch into marginally moist soil covered with a 1.5-inch dust mulch during 1999 and 2001, and 1.5-inch into moist soil during 2000. Wheat at Moro was planted on 1 October 2001 at 1.5-inch depth into moist soil. Temperature at the depth of seed placement, at the time of planting, was 59°F in 1999, 60°F in 2000, and 73°F in 2001 at Pendleton, and 59°F in 2001 at Moro. The experimental design was a split plot with variety as main plot and inoculum as subplots in blocks replicated four times. Data collected included emergence and stand density (October-December), plant growth and disease incidence and severity (March-May), whiteheads (June) and grain yield, test weight, and kernel weights (July-August). Plants were evaluated for grain yield by two methods. Genetic tolerance was assessed by harvesting plots with a plot combine and comparing yields of inoculated and noninoculated plots. Genetic resistance was assessed by digging plants from 3 ft of one row in each plot prior to machine harvest, and evaluating for each tiller the grain yield and the presence, absence, or degree of basal stem infection.

Early Generation Winter Wheat Breeding Lines

Effects of Fusarium crown rot were evaluated on early generation lines of winter wheat provided by Drs. Jim Peterson (Oregon State University) and Kim Campbell (USDA-Agricultural Research Service, Pullman, WA). Tests were performed on 75 wheat entries during 1999-2000 and 2000-2001, and 100 entries during 2001-2002. Test protocols and locations were as described above for the commercial varieties. Due to natural cycling of the selection process for early generation germplasm, only 32 of the 75 entries were tested during harvest year 2000 as well as 2001. Only 11 entries were in common for tests during harvest years 2001 and 2002.

Only four entries were tested during all three harvest years. Yields were measured only by machine harvest for these early generation entries, e.g., bundle samples were not collected.

Spring Wheat

Spring wheat varieties or breeding lines (42 entries) were evaluated for reaction to Fusarium crown rot at Moro during 2002. Drs. Kim Kidwell (Washington State University) and Bob Stack (North Dakota State University) provided entries for the screening nursery. The 20-year mean annual precipitation is 11.5 inch at Moro. Seed was planted into cultivated summer fallow. Wheat seed was treated and plots were inoculated and planted as described for winter wheat. Wheat was planted at 1-inch depth into moist soil on 18 March 2002. Seed-zone temperature was 34°F. Data included emergence and stand density (April), plant growth and disease incidence and severity (May), whiteheads (June), and grain yield, test weight, and kernel weights (August).

Australian Wheat

Six Australian wheat varieties with published characterizations for reaction to Fusarium crown rot were evaluated for this trait in eastern Oregon soils and climates. These varieties are used by the Queensland Department of Primary Industries as "standards" in screening nurseries for crown rot, and have been assigned a numerical "Disease Resistance Index" against which other breeding lines are compared. Drs. Graham Wildermuth (Queensland Department of Agriculture) and Hugh Wallwork (South Australian Research and Development Institute) provided the seed. Reaction to Fusarium crown rot was evaluated during two growing seasons at the Columbia Basin Agricultural Research Center stations near Pendleton and Moro, where 20-year mean annual precipitation is 17.9 and 11.5 inch, respectively. All fields were maintained as cultivated summer fallow for 14 months following winter wheat harvest. Plantings were made as winter wheat during 2000-2001 and 2001-2002 growing seasons, and also as spring wheat during 2002. Wheat seed was treated and plots were inoculated and planted as described earlier. The experimental design was a split plot with variety as main plot and inoculum as subplots in blocks replicated two times during 2000-2001 and four times for trials during 2001-2002. Winter wheat at Pendleton was planted on 22 September 2000 at 1.5-inch depth into moist soil and on 18 September 2001 at 3-inch depth into marginally moist soil covered with 1.5 inch of dust mulch. Winter wheat at Moro was planted on 1 October 2001 at 1.5-inch depth into moist soil. Seed-zone temperature at Pendleton was 60°F in 2000 and 73°F in 2001, and at Moro was 59°F in 2001. Spring wheat was planted at 1-inch depth into moist soil at Pendleton on 14 March 2002 and at Moro on 18 March 2002. Seed-zone temperature was 40°F at Pendleton and 34°F at Moro. Data included emergence and stand density (October-December), plant growth and disease incidence and severity (March-May), whiteheads (June) and grain yield, test weight, and kernel weights (July-August).

Results

Winter Wheat Varieties

Emergence at Pendleton during 1999 was slow and seedlings were stressed by low soil moisture; inoculum was in air-dry soil for 5 weeks until autumn rains began on 28 October. Rain began before planting at Pendleton during 2000 and Moro during 2001, and soils were continuously wet into the winter. Rain (0.36 inch) crusted soil prior to emergence at Pendleton during

2001. Growing-season precipitation (September-August) deviated from the 20-year mean during 1999-2000, 2000-2001, and 2001-2002 by +8, -7, and -27 percent at Pendleton, and -20, -46, and -26 percent at Moro. Spring-season precipitation (March-May) deviated from the 20-year mean during 1999-2000, 2000-2001, and 2001-2002 by +2, -17, and -32 percent at Pendleton, and +9, -22, and -35 percent at Moro.

Inoculum did not affect seedling emergence, plant stand, or plant tillering during the first 2 years at Pendleton or during 2001-2002 at Moro ($p < 0.05$; Table 1). Plant stands were strongly affected by an inoculum x soil crusting interaction at Pendleton during 2001; stand counts were 52 percent lower in inoculated than noninoculated plots (6.5 vs 13.4 plants/ft row, respectively; $p < 0.001$). Compared to plants affected by native levels of *Fusarium*, additional inoculum of the pathogen in all tests increased the incidence of plants with rotted crowns, the incidence and severity of lesions on subcrown internodes, and the percentages of whiteheads (Table 1). Inoculum reduced grain yield and usually also reduced test weight (Table 1).

Inoculation reduced yields of individual entries (Table 2) at Pendleton by 2-28 percent (11 percent mean) in 1999-2000, 0-22 percent (12 percent mean) in 2000-2001, and 32-85 percent (58 percent mean) in 2001-2002, and at Moro by 35-70 percent (55 percent mean). The greatest damage from Fusarium crown rot occurred on 'Coda', 'Connie', and 'Lewjain' (Table 3). Wheat varieties with overall best performance were 'Brundage', 'Gene', and 'Weatherford'. However, even the best varieties were damaged by extraordinary drought that occurred during 2001-2002, and especially when fungus spores were present near the cotyledon at a time when emergence was retarded by soil crusting before seedling emergence.

All yield observations noted above represented genetic tolerance or intolerance to infection, based on machine harvest. None of the entries retarded the ability of the pathogen to infect crowns and stem bases, as assessed by evaluating disease and yield parameters on individual tillers collected from 3-ft-row sections in each plot. Therefore, genetic resistance to *F. pseudograminearum* was not detected among the 18 winter wheat entries in these tests.

Early Generation Winter Wheat Breeding Lines

Rainfall and soil crusting were as described for the commercial varieties. Inoculum did not significantly ($p < 0.05$) affect seedling emergence, plant stand, or tillering during 1999-2000 and was not evaluated during 2000-2001. Inoculation increased the incidence of plants with rotted crowns, lesions on subcrown internodes, and whiteheads, and also increased the severity ratings for lesions on subcrown internodes. Inoculation reduced grain yield (110 vs 101 bu/acre in 1999-2000 and 86 vs 78 bu/acre in 2000-2001), and grain test weight during 1999-2000 (58.9 vs 58.2 lb/bu) but not 2000-2001 (mean of 58.6 lb/bu). Inoculation reduced grain yields 9 percent (range of 2-29 percent) in the year with a dry autumn but overall wet season (1999-2000) and 11 percent (range of 0-28 percent) in the year with a wet autumn but overall dry season (2000-2001). Most of the 32 entries tested during both seasons exhibited variable yield responses to *F. pseudograminearum* each year. However, several entries had minimal yield depression from inoculation both years (Table 4), including 'Altar 84' (5 and 0 percent), 'KS93U104' (2

Table 1. Influence of *Fusarium pseudograminearum* added to soil at the time of planting (inoculated), as compared to planting into soil with a "normal" background population of this pathogen (non-inoculated), on seedling establishment, disease incidence and severity, whiteheads, grain yield and test weight for 17 winter wheat and one triticale varieties (names are listed in Table 2).

Sampling parameter	Pendleton						Moro	
	1999-2000		2000-2001		2001-2002		2001-2002	
	Non-inoc.	Inoc.	Non-inoc.	Inoc.	Non-inoc.	Inoc.	Non-inoc.	Inoc.
Seedling emergence:								
Plant stand density (plants/ft row)	23	23	26	26	13	7 *	10	9
Disease intensity during early spring:								
Rotted crowns (percent)	13	54 *	tr	1	1	29 *	1	4 *
Lesions on sub-crown internode								
Disease incidence (percent)	6	45 *	30	38	65	88 *	38	58 *
Disease severity (0-4; 4 = severe)	1.1	3.0 *	1.6	2.5 *	1.5	2.7 *	1.8	2.1 *
Mature plants:								
Whiteheads (percent)	tr	1 *	1	4 *	-	-	8	29 *
Test weight (lb/bu)	55	55	57	55 *	60	59 *	54	51 *
Grain yield (bu/acre)	112	99 *	86	76 *	64	25 *	32	16 *
Yield reduction from inoculation (percent)	12		12		61		50	
Climatic conditions relative to disease:								
Autumn weather (stored water + rain)	dry		wet		dry **		dry	
Overall seasonal precipitation	wet		dry		dry		dry	
Relative "disease pressure"	moderate		moderate		high		high	

* Means for inoculated and noninoculated plots differed significantly (p = 0.05) where indicated by an asterisk (*).

** Rain caused severe preemergence soil crusting at Pendleton during September 2001. Crusting greatly amplified damage caused by the *Fusarium*. Stands were greatly reduced by crusting plus added *Fusarium*, compared to crusting alone. At Moro in September 2001, emergence was uniformly poor due to low moisture in the summer fallow.

Table 2. Tolerance of winter wheat and triticale to Fusarium crown rot in plots inoculated with *Fusarium pseudograminearum* at the experiment stations near Pendleton and Moro, Oregon, during harvest years 2000, 2001, and 2002. Data represent percent (%) yield reduction when the pathogen was added to plots, compared to a natural background level of the same pathogen.

Variety or line	Market class	Pendleton 1999-2000	Pendleton 2000-2001	Pendleton 2-year mean		Moro 2001-2002	Pendleton and Moro 3-site-year mean (2000-2002 harvests)		Pendleton * 2001-2002	Pendleton and Moro 4-site-year mean (2000-2002 harvests)	
		% loss	*% loss*	*% loss*	*rank*	*% loss*	*% loss*	*rank*	*% loss*	*% loss*	*rank*
Alzo	triticale	3	0	1.5	1	-	-	-	-	-	-
Gene	SW	5	9	7.0	4	39	17.7	1	57	16.0	2
Brundage	SW	4	4	4.0	2	50	19.3	2	60	16.0	3
Weatherford	SW	5	10	7.5	5	44	19.7	3	65	17.9	4
Lambert	SW	18	11	14.5	11	35	21.3	4	32	22.4	1
Tubbs	SW	4	14	9.0	7	47	21.7	5	59	20.3	5
Madsen	SW	2	13	7.5	5	57	24.0	6	65	21.1	8
Stephens	SW	21	9	15.0	12	47	25.7	7	68	26.0	12
Rohde	club	13	18	15.5	13	47	26.0	8	47	26.6	7
OR 943575	SW	15	14	14.5	11	52	27.0	9	56	26.6	10
Temple	club	2	10	6.0	3	70	27.3	10	48	22.8	6
Eltan	SW	6	10	8.0	6	70	28.7	11	39	25.0	5
OR 850513-8	SW	13	10	11.5	8	63	28.7	11	57	26.4	11
Rod	SW	4	20	12.0	9	63	29.0	12	70	27.0	13
Bruehl	club	12	15	13.5	10	64	30.3	13	45	28.6	9
Coda	club	23	19	21.0	15	49	30.3	13	85	31.5	15
Lewjain	SW	10	20	15.0	12	64	31.3	14	63	30.3	14
Connie	durum	28	19	23.5	16	69	38.7	15	67	38.6	16
Site-year mean		10.4	12.5	-	-	54.7	-	-	57.8	-	-
lsd (p = 0.05)		2	3	2	-	22	17	-	26	13	-

* Rain caused severe preemergence soil crusting at Pendleton during September 2001. Crusting greatly amplified damage caused by the *Fusarium*. Stands were much reduced by crusting plus added *Fusarium*, compared to crusting alone. The effect of the pathogen acting alone was more accurately represented by the 3-site-year mean than 4-site-year mean, although rankings of individual varieties were generally similar for those two comparisons.

Table 3. Groupings of winter wheat varieties according to tolerance rankings for Fusarium crown rot in four field trials reported in Table 2.

Relative rankings in Table 2	Varieties
always less than or equal 5	Alzo, Brundage, Gene, Weatherford
always less than or equal 10	Madsen, Temple, Tubbs
always more than or equal 5	Bruehl, Rod, Rohde, Stephens, OR943575, OR850513-8
always more than or equal 10	Coda, Connie, Lewjain
variable: sometimes <5 and sometimes >10	Eltan, Lambert

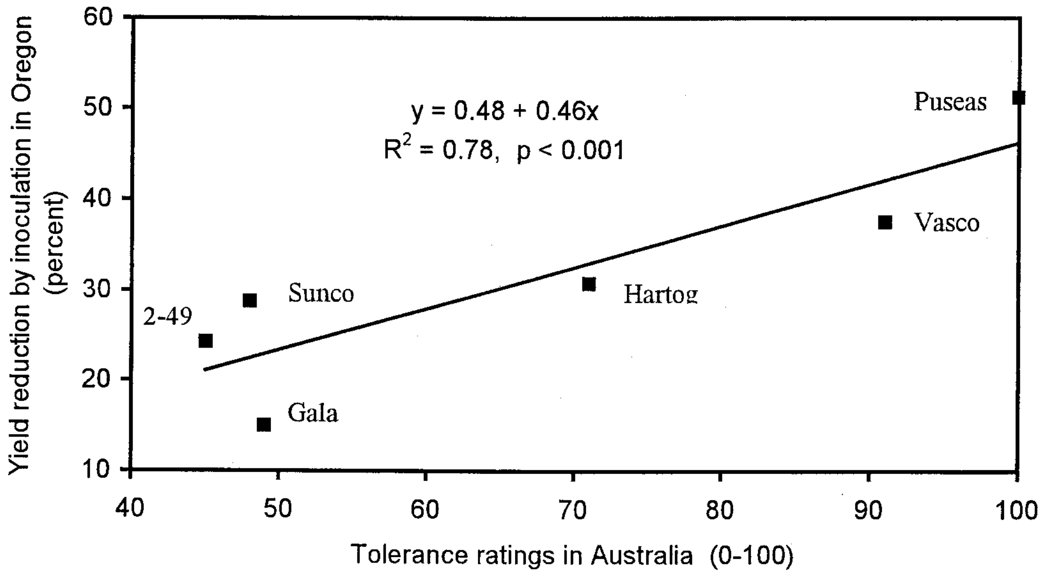

Figure 1. Performance of six Australian wheat varieties in field plots inoculated with *Fusarium pseudograminearum*, or not inoculated, at Pendleton and Moro, Oregon, during 2000, 2001, and 2002; comparison of resistance ratings designated in Australia and tolerance to Fusarium crown rot when produced in Oregon.

Table 4. Tolerance of winter wheat to Fusarium crown rot in plots inoculated with *Fusarium pseudograminearum* at the experiment stations near Pendleton and Moro, Oregon, during harvest years 2000 and 2001. Data represent percent yield reduction when the pathogen was added to plots, compared to a natural background level of the same pathogen.

Entry	Market class	Origin	1999-2000	2000-2001	2-year mean
			percent yield reduction		
OR942504	HW	Oregon	0	0	0
KS93U161	HR	Kansas	2	0	1.0
KS93U104	HR	Kansas	2	1	1.5
Altar 84	D	CIMMYT	5	0	2.5
KS93U134	HR	Kansas	5	0	2.5
VHO 091505	SW	Washington	8	3	5.5
Rossini	R	France	1	11	6.0
Bolero	R	France	13	0	6.5
OR942494	HW	Oregon	7	6	6.5
KS93U50	HR	Kansas	9	5	7.0
OR943560	SW	Oregon	8	7	7.5
OR9800924	R	France	0	15	7.5
U3445-23-1-1	HR	Kansas	4	12	8.0
KS96WGRC34	HR	Kansas	2	15	8.5
OR941044	HW	Oregon	3	14	8.5
OR941898	SW	Oregon	15	2	8.5
OR941904	SW	Oregon	4	13	8.5
KS91WGRC11	HR	Kansas	8	11	9.5
MV 230-96	R	Hungary	3	17	10.0
OR9800925	R	France	9	11	10.0
Valois	R	France	12	8	10.0
OR941611	SW	Oregon	6	15	10.5
OR941899	SW	Oregon	7	15	11.0
OPATA 85	D	CIMMYT	18	5	11.5
OR943576	HW	Oregon	9	14	11.5
ORD948927	D	Oregon	17	6	11.5
U2657-2-28-5	HR	Kansas	9	14	11.5
OR941345	SW	Oregon	19	10	14.5
N96L1226	HR	Nebraska	10	21	15.5
WGRC23	HR	Kansas	6	28	17.0
Stephens	SW	Oregon	23	13	18.0
OR9800919	R	France	18	21	19.5
lsd (p = 0.05)			13	ns	--

and 1 percent), 'KS93U134' (5 and 0 percent), 'KS93U161' (2 and 0 percent), 'OR942494' (7 and 6 percent), and 'OR942504' (0 and 0 percent). Some entries also had highly negative yield responses to *F. pseudograminearum* during both years, including 'N96L1226' (10 and 21 percent), 'OR941345' (19 and 10 percent), 'OR9800919' (18 and 21 percent), and 'Stephens' (23 and 13 percent).

Four of the 32 entries described above were tested at Pendleton and Moro during 2001-2002. None of those entries represented the highly tolerant entries tested during the two previous years. Likewise, 11 entries were examined during both 2000-2001 and 2001-2002. There was no commonality in response during the years of moderate and high disease pressure.

Fusarium crown rot reduced the grain yield for all market classes of wheat (data not shown). Average yield reductions were almost identical for market classes soft white common, soft white club, hard red, hard white, and soft red; reductions of 7-11, 10-12, and 51-61 percent occurred in 1999-2000, 2000-2001, and 2001-2002, respectively. Durum wheat had higher levels of grain yield reduction during 2 years (18 percent in 1999-2000 and 69 percent in 2001-2002) and a lower level of reduction (8 percent) during 2000-2001.

Spring Wheat

Growing-season precipitation (September-August) at Moro deviated from the 20-year mean during 2000-2001 and 2001-2002 by -46 and -26 percent, respectively. Spring-season precipitation (March-May) deviated from the 20-year mean during 2002 by -35 percent. Under these highly stressful conditions, inoculum had a particularly strong influence in elevating the disease severity and reducing grain yield. Entries had highly variable responses to Fusarium crown rot (Table 5). Some entries were heavily damaged (e.g., 'WA7902', 'WA7901', 'Butte 86') and others had little measurable impact (e.g., 'Parshall', 'WA7925', 'ND744'). Since this report includes only one site and year for the spring wheat trial, it remains unknown whether these responses will vary over years and locations.

Australian Wheat

Rainfall conditions were as described for the winter and spring wheat tests. Inoculum did not affect seedling emergence, plant stand, or plant tillering ($p < 0.05$). Inoculum increased the incidence of rotted crowns, lesions on subcrown internodes, and whiteheads, and reduced grain yield. The varieties in Australia are classed as very susceptible ('Puseas'[100]), susceptible ('Vasco'[91] and 'Hartog'[71]), moderately resistant ('Sunco'[48] and '2-49'[45]), or resistant ('Gala'[49]). Numbers in superscripts are numeric indices assigned to describe the relative level of resistance in Australia. All comparisons are made with respect to the response by 'Puseas', the "standard" for anticipated highest level of susceptibility for entries planted into each test. 'Puseas' was also the most susceptible variety in these Oregon-based tests, and '2-49' and 'Gala' were most tolerant (Table 6). During four site-years, including inoculated and noninoculated stands grown as either winter or spring wheat, the Australian indices for six "standards" were correlated with percentage yield reduction caused by inoculation with *F. pseudograminearum* in Oregon (Fig. 1). Varietal responses to Fusarium crown rot in Australia and in Oregon were therefore similar; those varieties with highest resistance indices in Australia also had the lowest levels of differential yield reduction when additional pathogen was added to the soil in Oregon.

Table 5. Response of 16 spring wheat entries (representative of 42 entries tested) to inoculation of soil with *Fusarium pseudograminearum* at Moro, Oregon, during 2002. Data are percent yield reductions when the pathogen was added to plots, compared to a natural background level of the same pathogen in adjacent plots.

Intolerant entries	Yield reduction	Tolerant entries	Yield reduction
	percent		*percent*
WA7902	43	WA7919	17
WA7901	41	WA7904	17
Butte 86	40	Tara	14
Calorwa	39	Grandin	13
Macon	35	WA7906	12
Zak	31	Parshall	5
Scarlet	28	WA7925	4
Westbred 926	24	ND744	0
mean	35	mean	10

Table 6. Yield stability for six Australian wheat varieties in the presence of *Fusarium graminearum* in Oregon soils; the varieties differ in tolerance to Fusarium crown rot in Australia and were grown as winter and spring wheats in four trials at Pendleton and Moro, Oregon, during harvest years 2001 and 2002.

Variety	Tolerance rating in Australia[a]	Tolerance score in Australia[b]	Pendleton 2000-2001 winter wheat	Pendleton 2002 spring wheat	Moro 2001-2002 winter wheat	Moro 2002 spring wheat	Four site-year mean
			percent yield reduction caused by inoculation with the pathogen[c]				
2-49	MR	45	14	59	15	9	24
Gala	R	49	0	48	0	12	15
Hartog	S	71	0	58	50	15	31
Puseas	VS	100	28	78	57	42	51
Sunco	MR	48	8	45	27	35	29
Vasco	S	91	18	67	44	21	38

[a] Published listings of susceptibility to Fusarium crown rot caused by *Fusarium pseudograminearum* in Australia.
[b] Quantified reaction ratings ("Index of Susceptibility") assigned as standards for comparison in crown rot screening nurseries performed by the Queensland Department of Primary Industries.
[c] Yield reductions in replicated plots inoculated with *Fusarium pseudograminearum*, as compared to adjacent non-inoculated plots.

Discussion

Genetic tolerance to Fusarium crown rot is important during years when the disease pressure is moderate. Tolerance is not needed when disease pressure is low, and is ineffective when disease pressure is high. Tolerance is, however, a very effective means for reducing economic damage during many years in areas where this disease causes chronic damage. Table 3 presents relative disease tolerance rankings for commercial varieties grown during years of diverse rainfall patterns. The best varieties were 'Brundage', 'Gene', and 'Weatherford'. Others, including 'Madsen', 'Temple', and 'Tubbs' are also reasonable choices if they have more desirable performance criteria in a particular production area, compared to the most disease tolerant varieties.

Preliminary evidence suggests that germplasm exists that is capable of yielding very well in the presence of Fusarium crown rot. This was especially true for the early generation lines 'OR942504', 'KS93U104', and 'KS93U161'. However, these lines were not tested during 2001-2002 when crown rot was most severe. Nevertheless, these lines should be examined further for their potential to serve as parents in breeding programs.

Durum wheat is noted internationally for being exceptionally susceptible to damage by Fusarium crown rot. Although few durum varieties have been tested in Oregon, this market class was represented by the most susceptible of winter wheat varieties tested (e.g., 'Connie'), and by highly susceptible early generation breeding lines. However, great variability occurred among entries in every market class. It appears from these results that the heritage of individual lines may be more important than market class per se, with respect to damage that can be anticipated by Fusarium crown rot.

Spring wheat lines and varieties also differed greatly in response to Fusarium crown rot. These lines have not been tested for enough years to determine if the performance at Moro during 2002 is a stabile feature for these entries.

Australian wheat varieties were imported to determine if Pacific Northwest varieties were near the top, middle, or bottom of the range in crown rot susceptibility described overseas. Our tests show that local varieties span the full range of susceptibilities described in Australia. Also, these tests show that our tests can be compared to results of future research in Australia if the Australian varieties continue to be included in tests conducted in the Pacific Northwest. 'Gala' and '2-49' are particularly interesting as potential parents for genetic tolerance in breeding programs. 'Sunco' performed quite well and is also a potential parent for breeding because it is used as a "standard of excellence" in end-use quality testing programs overseas. Each of these Australian varieties may prove useful in Pacific Northwest wheat improvement programs. Each of these varieties has produced much higher yields when grown as winter than spring wheat in the Pacific Northwest, and each has survived all winters tested thus far (from 1999-2000 to 2002-2003) at Pendleton, Moro, and Lind (WA).

As described earlier, genetic tolerance is useful during many years. But tolerance is likely to fail during years when protection is most urgently required. Also, it is not feasible to screen all or even high numbers of entries at the early-generation level. A program of that type would be much too costly and breeding programs cannot retain germplasm long enough for thorough testing for this disease alone. Breeding programs make judgments for a multitude of selection criteria. It became clear that entries with apparent tolerance to Fusarium crown rot were usually dropped from breeding programs based on other selection criteria. It was also clear that the number of entries tested in the field each year (<100) was much too small to have a reasonable chance to detect genetic resistance, which may occur in only a fraction of one percent of the germplasm. This screening program for tolerance to Fusarium crown rot therefore needed to be redirected.

Current efforts with Fusarium crown rot are being shifted to a search for genetic resistance. Field tests are not well suited to this pursuit. We are therefore adopting a system currently being used in Australia and Syria. That system involves testing large numbers of individual plants in small pots. Seedlings are started in the greenhouse and then are moved outdoors onto a sandbed for further growth and maturation. But in fact, almost all plants will die before maturing when seedlings are challenged by one or more of these pathogens. Thus, the numbers are reduced rapidly. Seed is collected from the few surviving plants and the test is repeated to determine if the seedling simply escaped being infected, as opposed to demonstrating true resistance. If the promising lines survive a second generation of screening, they are advanced to head row tests in the field, in a manner that we currently use to evaluate genetic tolerance. Lines that perform well in head row tests are transferred back to breeding programs for use in crossing blocks. Progeny of the crosses are then re-examined in the greenhouse screening system, or are examined using DNA marker-assisted breeding techniques to detect the gene(s) that confer resistance. This search for genetic resistance is being accelerated by developing collaborative testing protocols with international wheat research testing programs that are already using tests of this type to screen for resistance to Fusarium crown rot in winter and spring wheat.

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SOIL CARBON TRENDS IN PACIFIC NORTHWEST WHEAT-FALLOW SYSTEMS

Steve L. Albrecht, Stephen Machado, and Dale Wilkins

Abstract

In the Columbia Basin, summer rainfall is inadequate for warm-season crops, but the area is well suited for winter annuals and cool-season grasses. Although winter wheat yields in the region have increased over time, soil carbon and organic matter have continued to decline under the winter wheat/summer fallow rotation common in this area--even where soil erosion is minimal. In the 1930's, several long-term experiments were started at the Pendleton Experiment Station in northeastern Oregon to evaluate the effects of fertilizer, residue management, and tillage on crop productivity in the cereal-producing, dryland regions of the Columbia Basin. A chronosequence of soil carbon determinations from the long-term experiments was evaluated. Soil carbon declined in all conventional management systems, except when substantial organic amendments were applied. Nitrogen fertilization reduced the soil carbon decrease; however, residue burning intensified soil carbon loss. Manure applications increased soil carbon in the upper depths, but even with manure additions, soil carbon below 12 in declined over time. Soil carbon in the upper 12 in increased substantially under a grass pasture management. We concluded that the wheat/fallow system is very detrimental to maintaining soil carbon.

Key Words:
Carbon sequestration, long-term experiments, organic matter, residue management, soil quality

Introduction

Soil organic matter (SOM) is an important component of soil productivity; carbon (C) comprises about 51 percent of the SOM. It is estimated that the prairie grasslands of the Columbia Plateau required more than 10,000 years to reach a stable SOM content. Large areas of northeastern Oregon and southeastern Washington were first cultivated in the late 1880's. At the outset, these lands were very fertile; however, immediately following cultivation they lost a substantial amount of their SOM. Frequent cultivation to control weeds removed surface vegetation, accelerated water and wind erosion, and intensified the loss of SOM.

A management system that incorporates wheat/fallow rotations, moldboard plowing, and rod weeding is used on 4.5 million acres in north-central Oregon and south-central Washington. This system is considered economical where rainfall is inadequate to produce a profitable crop every year (Leggett et al. 1974; Bolton and Glen 1983). This system is used primarily to store winter precipitation and control weeds; additional reasons for its use include the accumulation of nutrients from the decomposition of residue and SOM, lower incidence of disease, and fewer problems with residue during tillage or seeding operations. In addition, grain yields are usually less variable over time with this system. The fallow period during summer, however, is detrimental to SOM. The system can increase soil erosion and is not biologically sustainable (Rasmussen and Parton 1994).

The development of high-yielding semi-dwarf wheat varieties with high water-use efficiency and disease resistance has not compensated for the decline in biological sustainability of soils in the Pacific Northwest (PNW) (Duff et al. 1995). Since the 1950's, economic sustainability has also declined in PNW fallow cropping systems because costs continue to rise while wheat prices remain stagnant (Duff et al. 1995).

Long-term experiments are feasibly the only way to determine if agricultural management systems will improve, sustain, or degrade the productive capacity of the soil. They can direct agricultural operations by identifying the effects of management practices on soil quality and crop yield. The Pendleton Experiment Station (PES) was established in 1928 to develop farming systems that improve productivity, sustain soil fertility, and reduce erosion; a short time later several long-term experiments were begun. Two of these, the Crop Residue experiment (CR) and the Grass Pasture experiment (GP) were started in 1931. The CR was designed to assess the sustainability of the conventional wheat/fallow rotation. The objective was to determine the effects of N application, residue burning, and pea vine and manure application on soil properties and productivity in a conventional moldboard plow, winter wheat/summer fallow production system. The GP, simulating perennial grassland, was initiated to enable a comparison with intensively managed areas. The overall goal of the GP was to approximate native productivity without fertilizer, irrigation, and tillage.

The purpose of this investigation was to analyze the changes in soil C concentrations in relation to residue management practices in a summer fallow/winter wheat system. Soil carbon content was evaluated in relation to treatment duration and soil depth.

Materials and Methods

The PES has a Mediterranean climate. The 50-year annual average precipitation is 16.7 in, and the average annual temperature is 60° F. The soil is a Walla Walla silt loam (coarse, silty, mixed mesic, Typic Haploxerolls). The physical and chemical properties of this soil were reported by Pikul and Allmaras (1986).

The CR rotation is winter wheat/fallow with moldboard plow tillage. The experimental design is an ordered block consisting of nine treatments and two replications. The experiment contains duplicate sets of experiments that are offset by 1 year so that data can be obtained annually. Plot size is 38 by 132 ft. Replicates differ in soil depth, slope, and soil N content. Fall stubble burns are conducted in late September. Spring stubble burns are implemented and organic amendments applied in the spring of the fallow year. Late-winter or early-spring herbicides are used to control vegetative growth in wheat stubble until plots are plowed. Plots are plowed 8 in deep within 3 days after spring burning. The soil is then smoothed with a field cultivator/harrow. Weeds are controlled by tillage during the fallow phase and with herbicides during the crop phase. Nitrogen fertilizer is applied before seeding. The C and N content of the upper 24 in of soil has been determined about every 10 years (1931, 1941, 1951, 1964, 1976, 1986, and 1995).

The GP experiment contains no experimental variables. It is 150 ft wide by 360 ft long, and is divided by a waterway. Slopes range from 0 to 3 percent, and soil depth is about 4 ft. It is periodically reseeded with introduced grass selections, occasionally fertilized, and infrequently irrigated. It was grazed until 1985 but not since; however, the grass is clipped once or twice during summer growth.

A profile of the PES long-term experiments, including the CR and GP, was provided by Rasmussen and Smiley (1994).

Soil samples for chemical analysis were air-dried, put through a nine-mesh (Tyler) sieve, and finely ground on a roller mill. Carbon was determined by the loss on ignition procedure until 1976, thereafter by a carbon nitrogen analyzer (Alpkem and Fisions).

Results and Discussion

In both of the management systems examined--winter wheat/summer fallow, and moldboard plow with rod-weeding--soil C has consistently declined from 1931 to 1995 (Figs. 1– 4). When residue was burned and no N fertilizer was applied, the loss rate of soil C was most severe (Fig. 1).

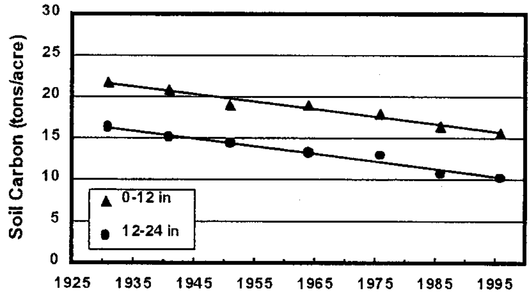

Figure 1. Changes in soil carbon in the top 24 in of soil with fall residue burn and no N treatment from 1931 to 1995 at the Pendleton Experiment Station, Oregon.

The addition of N fertilizer diminished the rate of decline in soil C; however, it did not prevent soil C loss over time (Figs. 2 and 3). Also, the addition of pea vines, at a rate of 1 ton of dry vines per acre before planting over a 65-year period, did not preclude soil C loss or substantially alter the rate of loss (Fig. 4). The only system that showed even a slight increase in the soil C level over the 65-year period was when animal manure was applied, at a rate of 10 tons (wet) per acre before seeding.

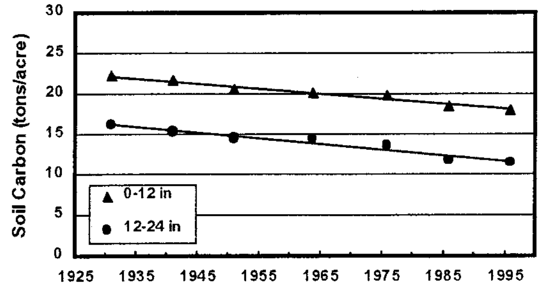

Figure 2. Changes in soil carbon in the top 24 in of soil with 40 lb N per acre from 1931 to 1995 at the Pendleton Experiment Station, Oregon.

The rate of soil C loss was similar at all depths, except in the 0- to 12-in depth there was a slight increase in C with manure application. Even with manure additions, the soil C at the 12- to 24-in depth declined at a rate similar to other management systems.

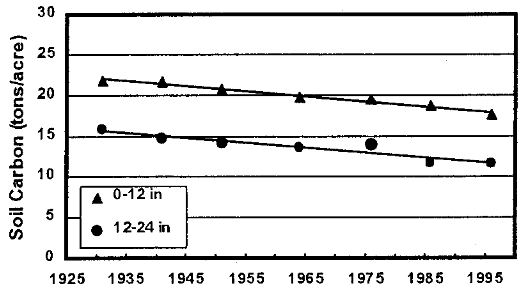

Figure 3. Changes in soil carbon in the top 24 in of soil with 80 lb N per acre from 1931 to 1995 at the Pendleton Experiment Station, Oregon.

While the amount of C data collected for the GP experiment is not as extensive as for the CR experiment, the long-term trends in soil C are evident. The GP showed a substantial increase in soil C in the upper soil depths from 1931 to 1995 (Fig. 6). However, at the 12- to 24-in depth the soil C remained essentially the same. This indicates that C is not being produced or transported to the lower depths. This suggests that summer fallow and tillage can impact soil C at depths below 12 in and intensify loss of soil

C and SOM throughout the profile. While the grass pasture is not an economically viable system, it is included to indicate what is possible in a system without summer/fallow and tillage.

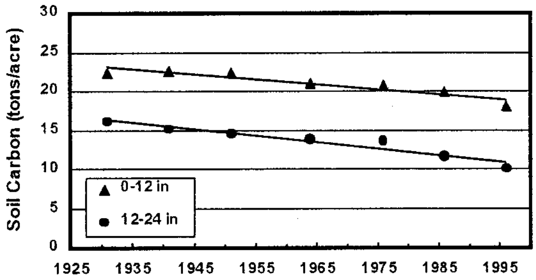

Figure 4. Changes in soil carbon in the top 24 in of soil with pea vine additions from 1931 to 1995 at the Pendleton Experiment Station, Oregon. Pea vines added at a rate of 1 ton per acre each crop year.

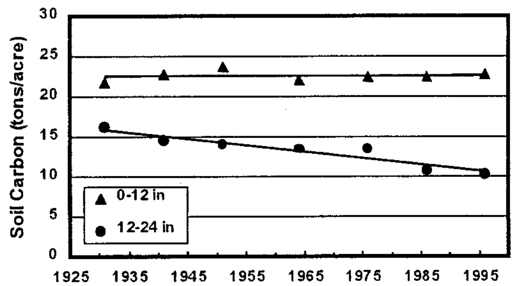

Figure 5. Changes in soil carbon in the top 24 in of soil with manure addition from 1931 to 1995 at the Pendleton Experiment Station, Oregon. Manure added at a rate of 10 tons (wet) per acre each crop year.

Loss of soil C, and also SOM, is generally attributed to microbial action. Burning residue depletes C input into the soil and precludes residue conversion to SOM. Plowing inverts the residue, making it more accessible to soil-dwelling microorganisms. Plowing will also change the gas composition in the soil by reducing carbon dioxide and increasing oxygen. Increasing the oxygen concentration will stimulate aerobic microorganisms by increasing their metabolic activity with the concomitant conversion of residue and SOM to carbon dioxide. Summer fallow is detrimental to

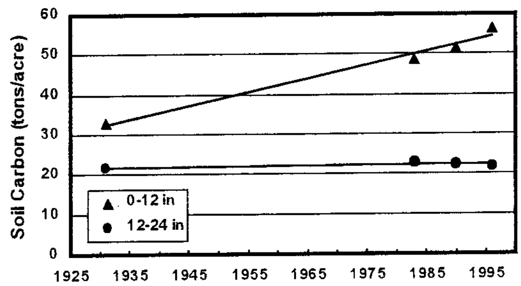

Figure 6. Changes in soil carbon in the top 24 in of soil under grass pasture from 1931 to 1995 at the Pendleton Experiment Station, Oregon.

SOM because it will generally reduce residue production, thereby reducing the material that can eventually be converted to SOM. Fallow ground also provides an environment with good soil moisture during the warm summer months. This condition favors microbial activity that will reduce residue and also SOM.

Conclusions

After 65 years, the soil C content, although dynamic, varies for different cropping systems. In contrast to almost all cultivated systems, the continuous grass-pasture soil showed an increase in C content. A conventional management system, with moldboard plowing and residue burning, results in more soil C loss than no-till or reduced tillage management. Soil C content can be increased with amendments such as manure.

The wheat/fallow system is very detrimental to soil C content. Residue additions are decreased and, although the fallow system reduces evapotranspiration and saves water for the upcoming crop, the soil moisture in the fallow phase of the rotation promotes microbial oxidation of SOM during the hot summer months. Simply put, continued removal of C and associated nutrients will result in further deterioration in soil quality and productivity.

Acknowledgements

We thank Roger Goller, Katherine Skirvin, Amy Baker, and Chris Roager for sample collection and technical assistance, and Bob Correa and Karl Rhinhart for farm operations. We also thank Katherine Skirvin and Steve Petrie for helpful discussions, and Paul Rasmussen, Richard Smiley, and Steve Petrie for management or operational support.

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CHEMICAL FALLOW WATER STORAGE IN A LOW PRECIPITATION ZONE OF NORTH-CENTRAL OREGON

Larry K. Lutcher

Abstract

Farmers in north-central Oregon use tillage fallow (TF) to store soil moisture for winter wheat produced the following year. Chemical fallow (CF) is an alternative to the conventional, tillage-based system. Utilization of CF has been limited due, in part, to concerns about soil water storage. This project was designed to compare CF and TF water storage in a production zone characterized by deep soils, limited annual precipitation (8-12 in), and dry, hot summers. Soil water storage in side-by-side CF and TF Ritzville silt loam profiles was compared at six sites in 2001 and at four additional sites in 2002. Water storage comparisons were made by evaluating the gravimetric water content of samples collected from each foot of the soil's profile. Water storage in CF, with 1.5 tons residue/acre, was statistically similar to that observed in TF. Results from statistical analysis of a smaller data set indicate water storage in CF might be increased if the amount of residue from the previous year's crop is approximately 4.5 tons/acre. Additional work is needed to verify effects of the quantity of post-harvest residue on water storage in CF.

Key words
Chemical fallow, conventional fallow, soil water storage, tillage fallow, winter wheat

Introduction

Winter wheat production in north-central Oregon occurs mostly on deep soils and in areas where average annual precipitation ranges from 8 to 12 in. Summers are dry and hot. Wheat is normally grown after a year of tillage fallow (TF). An alternative to conventional, tillage-based fallow is chemical fallow (CF). A renewed interest in CF can be attributed to (1) improvements in direct-seed equipment, (2) limited success with annual cropping, (3) repeated failures to grow alternative crops economically, and (4) the recent availability of a soil-active herbicide that may improve control of troublesome weeds such as kochia (*Kochia scoparia*) and Russian thistle (*Salsola kali*). Optimism about this alternative fallow method, though, is tempered by speculation of inadequate water storage. The objective of this project was to compare CF and TF water storage in representative fields of the region.

Materials and Methods

Plot Layout and Field Locations

Soil water storage in side-by-side CF and TF plots was compared at six sites in 2001 and at four additional sites in 2002. Most sites were located within a 6-mile radius of 45° 34′ 9″ N, 19° 49′ 8″ W (Morrow County, Oregon). CF and TF plot areas were 3,600 ft^2 (60 ft x 60 ft). Each plot was a subset of a much larger field and was managed with standard practices for the area. CF and TF fields at three sites were located immediately adjacent to one another. The distance between CF and TF sampling areas ranged from 40 to 80 ft. CF and TF fields at the seven other sites were separated by either a county road or farm road. The distance between sampling areas at these locations ranged from 210 to 265 ft. This larger separation distance was used in an attempt to avoid "edge effects" that might have been encountered next to the road or in areas where "outside rounds" were made.

Growing Conditions

The soil at each of the 10 sites is a Ritzville silt loam (*course-silty, mixed, mesic Calciorthidic Haploxeroll*) with a slope of less than 2 percent, an effective rooting depth of 4 or 5 ft, and an available water holding capacity of about 8 in. Total precipitation in 2000-2001 and 2001-2002 was 9.89 and 7.94 in, respectively. Rainfall during each of the April 1st to June 30th growing seasons ranged from 25 to 30 percent of the year's total.

Field Operations, Cropping History, and Chemical Fallow Residue

TF was maintained with a single "sweep" operation in April or May, followed by rod-weedings as necessary. Stubble in CF was left "as is" following harvest. Weed control in CF was accomplished with applications of glyphosate, 2,4-D, and/or gramoxone. CF and TF plots were weed-free during the experiment. Soil disturbance in CF occurred only at planting time and after sampling was completed.

The cropping history at three sites included 2 years of TF and 1 year of soft white winter wheat production, followed by either CF or TF (2001 project year). The estimated amount of residue in CF plots was 4.5 tons/acre. Stubble height was 16-21 in. The cropping history at seven sites included 1 year of TF and 1 year of soft white winter wheat production, followed by either CF or TF (2001 and 2002 project years). The estimated amount of residue in CF plots, at these locations, was 1.5 tons/acre. Stubble height ranged from 4 to 7 in.

Soil Sampling, Moisture Determinations, and Statistics

Soil sampling was conducted on June 15th (± 7 days) and again on September 1st (± 3 days). Sampling took place at three randomly selected locations within each CF and TF plot. Samples, which were collected with a bucket auger, were removed from each foot of the profile and placed in a 5-gal bucket where they were mixed, by hand, for approximately 30 sec. A small portion of the mixed sample was placed into a 4-oz soil moisture can. Wet weights were determined in the field using a leveled and calibrated electronic balance. Dry weights were determined 24 hours after samples were placed in a 230°F oven. Calculation of the total water content of soil profiles (Tables 1 and 2) was accomplished by summing the product of volumetric water contents and soil depth (12 in) for each 1-ft layer. Volumetric water contents were calculated from gravimetric numbers and an assumed bulk density of 1.25 gm/cm^3. The statistical significance of data was determined by an analysis of variance procedure for a randomized block design that used sites as replications. Treatment means were separated using Fisher's protected least significant different test.

Results and Discussion

Data from this research is preliminary evidence of a relationship between potential water storage in CF and the quantity of post-harvest residue. Subsequent comparisons of water storage for the two fallow methods are discussed accordingly. Plots with small amounts of residue (1.5 tons/acre) will be referred to as "light-residue" CF. Plots with substantially more residue (4.5 tons/acre) will be referred to as "heavy-residue" CF.

Table 1. Average water content of seven side-by-side chemical fallow (light-residue) and tillage fallow plots in Morrow County, Oregon.

Date	Chemical fallow	Tillage fallow	$LSD_{(0.05)}$
	---------------------Water content (inches)-------------------		
June 15	5.48	6.03	NS^{+}
Sept. 1	5.18	5.85	NS^{+}

$^{+}$ Not significantly different

Light-residue Chemical Fallow

Water storage in the two fallow systems was statistically identical (Table 1). There was, however, a consistent trend of decreased storage in CF. Water storage in CF was 0.55 in less than that in TF on June 15th. Increased water storage in TF, on the earlier sampling date, is probably a consequence of primary tillage operations conducted in April or May. A single "sweep" operation reduces the bulk density of the top 6 in of the soil profile. The reduction in bulk density inhibits upward migration of water to the soil surface. Water on or near the soil surface is usually "lost" to the atmosphere. Rod-weeding operations during July and August maintained the "moisture cap" and reduced evaporative losses in TF.

The distribution of water in soil profiles was similar for light-residue CF and TF (Figures 1 and 2). Maximum water contents were measured in the second foot. Soil moisture values above and below this depth were very low and a sharp decrease in moisture, over time, was noted in samples removed from the top foot of the profile.

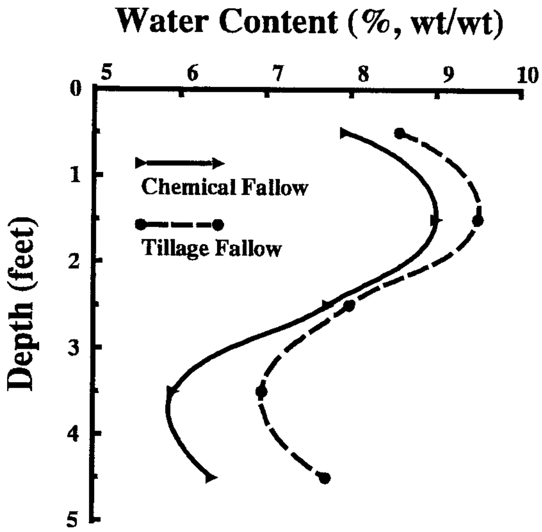

Figure 1. June 15th water content, by depth, for chemical fallow (light-residue) and tillage fallow plots. Data are from three Morrow County, Oregon sites where soil depth isequal to five ft.

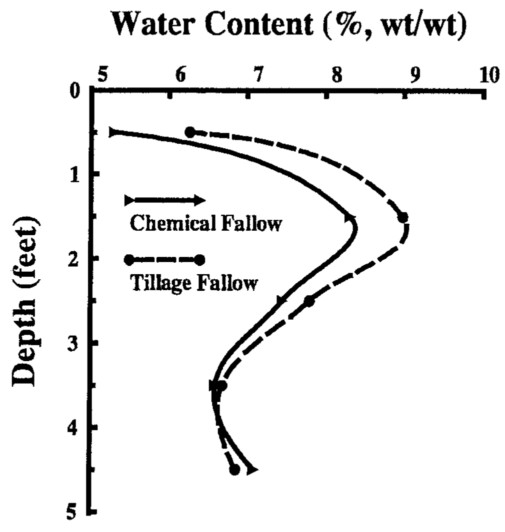

Figure 2. September 1st water content, by depth, for chemical fallow (light-residue) and tillage fallow. Data are from three Morrow County, Oregon sites where soil depth is equal to five ft.

Heavy-residue Chemical Fallow

The average water content of heavy-residue CF was significantly greater than that observed in TF (Table 2). The decreased amount of stored water over time was similar ($\approx$ 0.65 in) for both fallow methods. Increased CF water storage is, in all likelihood, the result of improved infiltration rates and a reduction in evaporative water loss, compared to light-residue CF, during July and August. The capillary continuity of an undisturbed soil surface layer remains intact. The soil is more effective at converting light rainfall into stored soil moisture.

Table 2. Average water content of three side-by-side chemical fallow (heavy-residue) and tillage fallow plots in Morrow County, Oregon.

Date	Chemical fallow	Tillage fallow	$LSD_{(0.05)}$
	---Water content (inches)---		
June 15	7.05	6.13	0.77
Sept. 1	6.41	5.46	0.86

Stem, leaves, and fractured pieces of stubble on the soil surface formed a fairly dense mat in some locations of the field. The overall effect of this mat on evaporation, however, was probably minimal, since it was observed infrequently within plot boundaries. Thick, standing stubble probably played a more significant role in reducing evaporation. A portion of the sun's incoming radiation, which is absorbed by the stubble, never reaches the soil. Heat input to the soil, relative to that of soils with little residue, is reduced during the summer. Standing stubble also reduces wind turbulence above the soil surface. Lower soil temperatures and reduced air movement decrease the vapor pressure gradient between the soil and the atmosphere. The effect is less evaporation.

The distribution of water in CF and TF profiles was similar on June 15th (Figure 3). Maximum water contents ranged from about 9.5 percent to almost 11 percent in the second foot. Soil moisture values above this depth decreased by approximately 1 percent. Minimum water contents were observed in the 4- to 5-ft soil layers.

The distribution of September 1st water in CF and TF profiles was not alike (Figure 4). Maximum CF water contents occurred in the second and third foot. Soil moisture values below 3 ft decreased by an average of 0.88 in/ft. The maximum water content in TF occurred in the second foot of the profile and decreased by an average of 0.58 in/ft in the 3-, 4-, and 5-ft layers. Soil moisture was minimal (≈ 7 percent) in the first and fifth foot. The dissimilar distribution of water may be related to differences in heat transfer (temperature gradients) between soil layers.

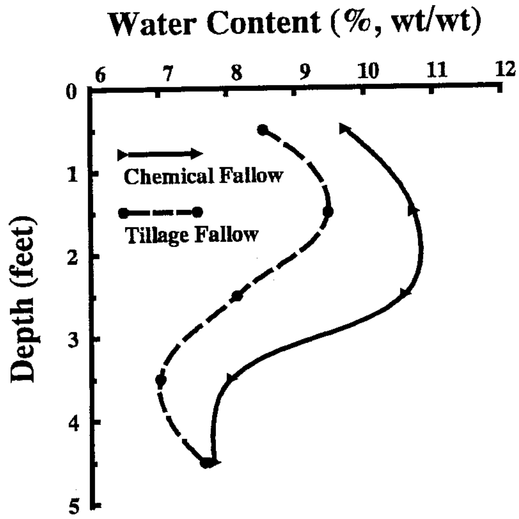

Figure 3. June 15th water content, by depth, for chemical fallow (heavy-residue) and tillage fallow plots in Morrow County, Oregon.

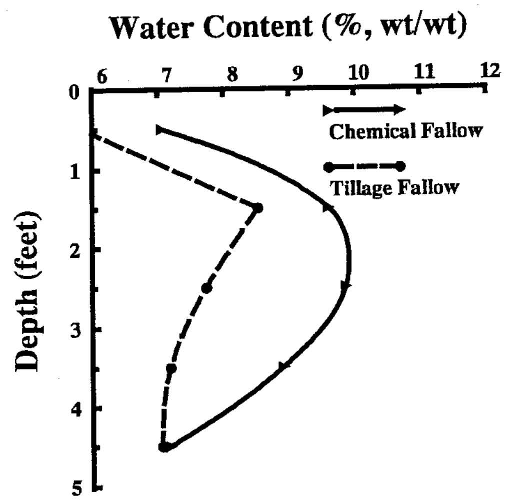

Figure 4. September 1st water content, by depth, for chemical fallow (heavy-residue) and tillage fallow plots in Morrow County, Oregon.

Conclusions

Readers are reminded that increased water storage with heavy-residue CF was observed at a very limited number of sites. Verification of results presented in this report will require additional research. Results from this project apply to CF and TF on Ritzville silt loams only. The storage of water and the distribution of water in heavy-residue CF will almost certainly be different for "heavier" or "lighter" soils. Year-to-year variations in temperature and precipitation will also have an influence on soil water storage.

CHEMICAL FALLOW SEED-ZONE SOIL WATER CONTENT IN A DRY FALL

Dale E. Wilkins, Stephan L. Albrecht, and Tami R. Johlke

Abstract

Lack of adequate seed-zone soil water content is one reason chemical fallow has not replaced tilled fallow in the inland Pacific Northwest winter wheat growing region. There is a lack of information concerning the influence of crop residue amount and length of continuous no-till on chemical fallow seed-zone soil water content. Seed-zone soil water content was measured in early October in chemical-fallow/winter wheat and tilled-fallow/winter wheat plots near Pendleton, Oregon. The chemical-fallow/winter wheat plots had varying amounts of wheat residue produced by the previous crop and length of time in no-till. In early October in a dry fall, seed-zone soil water content in no-till chemical fallow increased as wheat residue amount increased from 6,000 to 8,000 lb/acre. The seed-zone soil water content was slightly higher in plots that had been no-tilled for 22 years compared to water content in plots that had been no-tilled for 6 years. In an established no-till system with 7,200 lb/acre or more of crop residue, winter wheat stand establishment was equivalent to the conventionally tilled fallow system.

Key Words
Chemical fallow, crop residue, emergence, seed-zone, soil water, stand, winter wheat

Introduction

One of the reasons chemical fallow has not been widely adopted in the winter wheat (*Triticum aestivum* L) and fallow rotation in the Columbia Plateau is lack of adequate soil water in the seed-zone for wheat germination and emergence. Previous research has shown that a layer of dry dust mulch in a conventionally tilled wheat/fallow rotation conserved more seed-zone soil water than chemical fallow (Oveson and Appleby 1971, Lindstrom et al. 1974, Hammel et al. 1981, Wilkins et al. 2002). These results were based on a single amount of crop residue for each experiment. Only one of these experiments considered the effect of number of years in no-till. Wilkins et al. (2002) showed that water content in the seed-zone in mid-October tended to be higher after 17 years of no-till compared to first year no-till. Lutcher (2002) reported that the soil water in chemical fallow might be increased over tilled fallow if the previous year's crop residue was equal to or greater than 4,500 lb/acre. There is a lack of information on the effect of number of years in no-till and amount of crop residue on seed-zone soil water content for chemical fallow at seeding time in early October. Long-term chemical fallow no-till and conventionally tilled fallow experiments located at the Columbia Plateau Conservation Research Center (CPCRC) allowed the opportunity to examine the effect of amount of crop residue and years (6 and 22) of no-till or conventionally tilled fallow on seed-zone soil water and wheat emergence in a dry fall.

Methods

Gravimetric soil water content measurements were taken at the CPCRC on October 7, 2002 in an established chemical fallow experiment with four replications, five rates of nitrogen, and two varying lengths of continuous no-till (6 and 22 years of no-till), and also in an established conventionally tilled fallow experiment (Table 1). The amount of crop residue was determined for each plot by harvesting the above-ground plant material at maturity (July 2001) from an 11-ft^2 area, threshing and subtracting the grain weight from the above-ground plant material weight.

Three soil cores 0.75 inches in diameter were taken in each plot, sectioned into 0- to 2-, 2- to 4-, and 4- to 8-in increments, and composited by increments in all plots except the top two increments in the conventional tilled plots. In the 0- to 2- and 2- to 4-in increments in the conventionally tilled plots, a 2-in by 2-in incremental sampler designed for dust mulch sampling (Pikul et al. 1979) was used. Samples were oven dried at 220° F for 24 hours to determine soil water content.

'Stephens' winter wheat was seeded at the rate of 29 seeds per ft^2 on October 17, 2002 into the chemically fallowed winter wheat stubble and conventionally tilled fallow plot treatments indicated in Table 1. After the stubble was flailed, seeding was done with a Noble DK-5 drill equipped with openers modified to place liquid fertilizer below the seed after the stubble was flailed. This is a deep-furrow drill that was adjusted to place seed about 4 in below the soil surface. Emergence observations were made in these plots on November 29, 2002 and January 2, 2003.

Table 1. Amount of crop residue and wheat stand observations for experimental treatments in plots at the Columbia Plateau Conservation Research Center, Pendleton, Oregon, for the 2002 and 2003 crop year.

Treatments	Years no-till	Residue	Nov. 29	Jan. 2
Nitrogen lb/acre		lb/acre	----Plants/ft^2----	
0	6	4210	7.6 B*	22 A
40	6	6584	8.0 AB	19 A
80	6	7276	13.9 AB	19 A
120	6	8789	16.2 A	22 A
160	6	8080	14.2 AB	22 A
0	22	3986	5.9 BC	18 A
40	22	5951	3.6 C	21 A
80	22	7423	11.4 A	20 A
120	22	9338	10.9 AB	18 A
160	22	8160	14.0 A	20 A
120-Conv. Fallow	-	8117	13	20 A

*Numbers within a column for the same number of years in no-till followed by the same letter are not significantly different by the LSD test (P = 0.05).

Results

Table 1 shows the amount of winter wheat residue remaining on the plots after wheat harvest, at the beginning of the fallow period, in 2001. The amount of wheat residue increased as applied N increased from 0 to 120 lb/acre.

Dry weather in September and October is not unusual in the Columbia Plateau but the fall weather in 2002 was particularly dry (Table 2). Seed-zone soil water content was measured in 1997 in these same experiments (Wilkins et al. 2002). Precipitation that year was near the 70-year average in September and early October (Table 2).

Table 2. Monthly precipitation at Columbia Plateau Conservation Research Center, Pendleton, Oregon, for May through October 17 in 1997, 2002, and the 70-year average.

Month	1997	2002	70-year ave.
	----------inches----------		
May	0.46	1.02	1.49
June	1.10	1.39	1.22
July	0.36	0.23	0.34
August	0.02	0.00	0.49
September	0.88	0.24	0.72
Oct. 1-7	0.11	0.03	0.30
Oct. 1-17	0.26	0.07	0.72

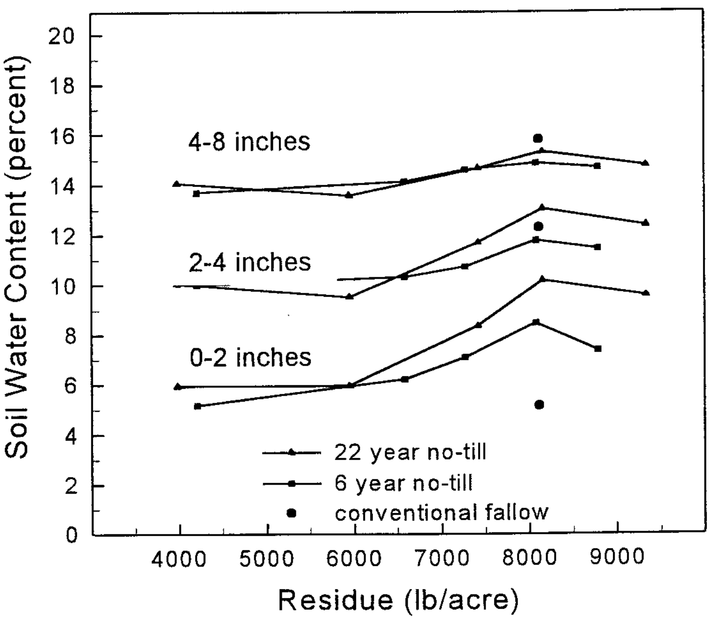

Figure 1. Effect of amount of crop residue on water content in the top 8 in of soil in tillage experiments at the Columbia Plateau Conservation Research Center, Pendleton, Oregon.

The influence of wheat residue amount on soil water content in the 0- to 2-, 2- to 4-, and 8-in increments on October 7, 2002 can be seen in Figure 1. Seed-zone soil water content did not change as wheat residue amount increased from 4,000 to 6,000 lb/acre, but as amount of wheat residue changed from 6,000 to 8,000 lb/acre seed-zone soil water content improved. There was more water in the top 2 inches in the chemical-fallowed plots as compared to the tilled-fallow plots. When the amount of wheat residue was 8,000 lb/acre, the soil water content in the 2- to 4- and 4- to 8-in increments was similar for the long-term no-till (22 years), short-term no-till (6 years), and conventional fallow.

Amount of soil water for germination and emergence was marginal (14 percent) at the 4- to 8-in depth in treatments with less than 7,000 lb/acre of residue. Figure 2 provides a comparison of the soil water content from the 0- to 10-in soil layer in a fall with average precipitation (1997) to a dry fall (2002). There was a small difference in soil water content between short- and long-term plots in each of those years in the no-till plots but the tilled-fallow plots had significantly more water in the top 10 inches in the year with average fall precipitation compared to the dry year.

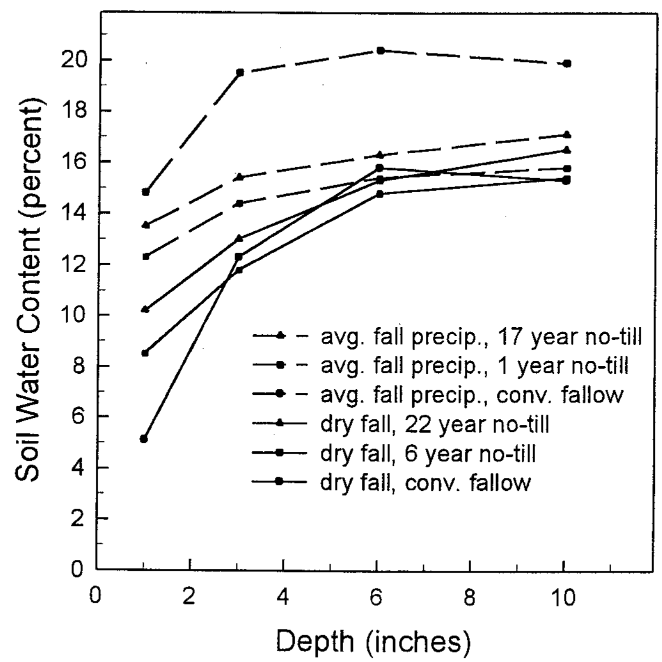

Figure 2. Comparison of soil water content in the top 10 in at seeding in chemical fallow and conventionally tilled fallow for normal and dry fall weather at the Columbia Plateau Conservation Research Center near Pendleton, Oregon.

Plant establishment data on November 29, 2002, when approximately 50 percent of the potential seedlings had established, are presented in Table 1. Plots with less crop residue and lower water contents had significantly fewer seedlings. Stand establishment in the chemical-fallow plots with 8,000 lb/acre or more of crop residue was equal to or better than stand establishment in the conventionally tilled fallow plots. On January 2, 2003 the stand establishment was not significantly different for any of the treatments.

Summary

During a dry fall, seed-zone soil water content in no-till chemical fallow in early October increased as wheat residue amount increased from 6,000 to 8,000 lb/acre. There was slightly more water in the top 8 in for 22 years of no-till compared to 6 years of no-till. With 7,200 lb/acre of wheat residue at harvest in the previous crop, seed-zone soil water content was equivalent to water content in conventionally tilled fallow and winter wheat stand establishment was similar in the chemical-fallow and tilled-fallow systems.

Acknowledgement

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SEED-SOIL CONTACT AND THE ROLE OF VAPOR IN GERMINATION

Stewart Wuest

Abstract

Seed-soil contact has been assumed to be the most important factor for rapid transfer of water from soil to seed. Recent research demonstrated that seeds are capable of germinating without soil contact, and that 85 percent or more of the water absorbed by seeds can be directly attributed to vapor. A new appreciation for the capacity of soil atmosphere to supply water vapor to seeds will help in future efforts to improve seeding equipment.

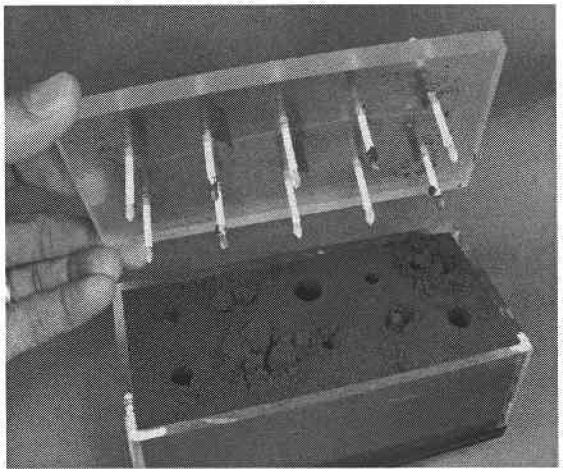
Key words
Germination, seeding equipment, seed-soil contact, water vapor

Placement and germination of seeds has been a concern in agriculture since the beginning. Thousands of years of experience, trial and error, and observation have lead us to the practices and equipment we use today. The current concept of how seeds absorb water from soil was based upon the idea that the seeds are in contact with minute water films on soil particles. From practical experience in touching wet objects, we could imagine that the dry seeds drew liquid water out of moist soil before beginning the process of germination. This led to the assumption that seed-soil contact was very important to rapid germination. Contrary to this logical and long-held assumption, my research has demonstrated that water vapor plays a big role in seed germination in the absence of irrigation or rain.

Theory and practice often co-exist quite happily, even when theory is later found to be incompatible with available knowledge. For example, when it was realized that it would be simpler to consider the earth as revolving around the sun, rather than vice versa, the average person did not need to change their daily routine, and there were no adjustments to make in the length of a day, or in using a calendar. In a similar sense, the revelation that water vapor is more responsible for seed germination than seed-soil contact has little immediate practical impact on our success as farmers. It should, however, help us make logical and effective choices in the future.

Water vapor is abundant in all but the driest soil. In fact, the relative humidity of soil air is above 99 percent at permanent wilting point (-15 bars water potential). It is close to 100 percent when the soil moisture is above -10 bars, the point at which Walla Walla silt loam soil starts to look dry. Even if soil air is below 100 percent relative humidity during the day, relative humidity will rise when temperatures drop at night, probably becoming supersaturated (slightly above 100 percent) for at least short periods. The consequence is that seeds can imbibe water in the form of vapor without physical contact between seed and soil.

To measure the contribution of vapor to water absorption by seeds, I needed a method to keep seeds from touching soil, but without a large gap for vapor to cross. The method adopted was a series of holes in a block of moist soil (Fig. 1). A wheat seed glued to a plastic stick was suspended in each hole. The holes ranged in size from no hole at all to 13-mm diameter (about one-half inch). In positions without a hole, the seed was forced directly into the soil and had maximum seed-soil contact. Since the wheat seed was about 3 mm in diameter, as the hole size increased, there was decreased



contact between the seed and soil. The soil was colored with blue dye, so the amount of seed-soil contact would be apparent after seed removal.

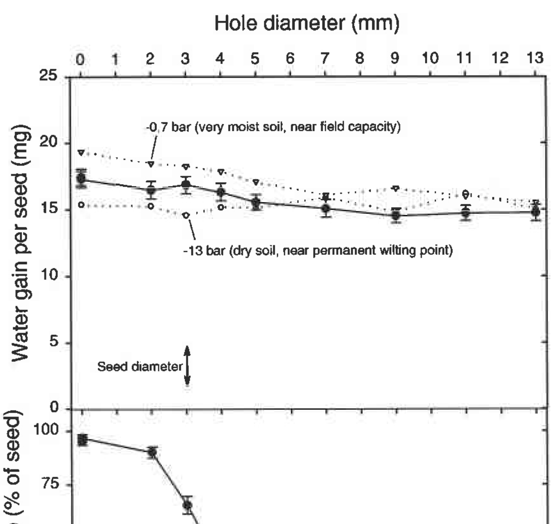


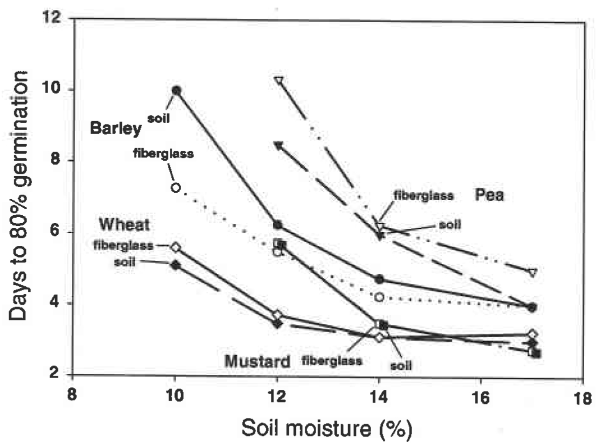
Figure 2 compares hole diameter to the amount of water taken up by wheat seeds after being suspended in the soil block for 24 hours, compared to the amount of dye covering the seeds. There was relatively little increase in water absorption by seeds as seed-soil contact and dye coverage increased from none to 100 percent. This indicates that the flow of liquid water through seed-soil contact is not the major source of water. The data were generated over a wide range of soil moistures. Some of the very moist and very dry data are shown separately in Figure 2. It is evident that soil moisture did not have a large influence on the amount of water absorbed.

Researchers question whether seeds absorb water only as liquid when soil contact exists, but as vapor when it does not. This is not likely unless the soil is very wet. Scientists have calculated how much contact a seed might have with soil (Collis-George and Hector, 1966). Only about 10 percent of a seed's surface theoretically would be touching liquid water films in a soil near field capacity, meaning 90 percent would still be exposed to soil atmosphere. In addition, as soon as a dry seed came in contact with liquid water, water would be absorbed by the seed, resulting in thinner water films and less seed contact. I believe our assumption that seeds often make effective contact with soil water films is erroneous.

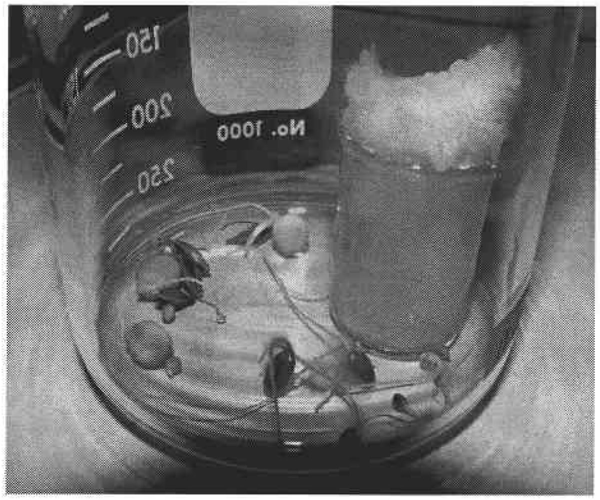
In the past, scientists have tried to correlate liquid water movement in soil to the rate at which a seed absorbs water, and they have encountered a problem. Seed germinates within days whether the soil is quite moist (near field capacity) or almost dry (about -10 bars water potential). We know that as soil gets dry, water movement in the soil slows exponentially. (That is, if water can move 2 mm per day in a particular soil at –0.1 bar water potential, water will only move 0.02 mm per day when the soil dries to –1 bar, and only 0.002 mm per day when the soil dries to –10 bars.) Not only would moisture move much, much more slowly as the soil dries and the water films thin, but seeds would have to draw water from a much greater distance to germinate.

Again, what we observe under laboratory and field conditions is that seed will germinate at nearly the same rate when planted in a wide range of soil moistures. Our explanation is that water vapor remains at nearly 100 percent over a wide range of soil moistures, from field capacity to fairly dry. This also explains why such a wide variety of drills, with and without packer wheels, in tilled or untilled soil, all are capable of producing good stands. Some farmers seed with drills they know are producing "poor" seed-soil contact, and then follow seeding with a light harrow to cover the seed with a loose layer of soil. Large, uniform fields of emerging wheat would be a rare sight if germination were highly dependent on good seed-soil contact.

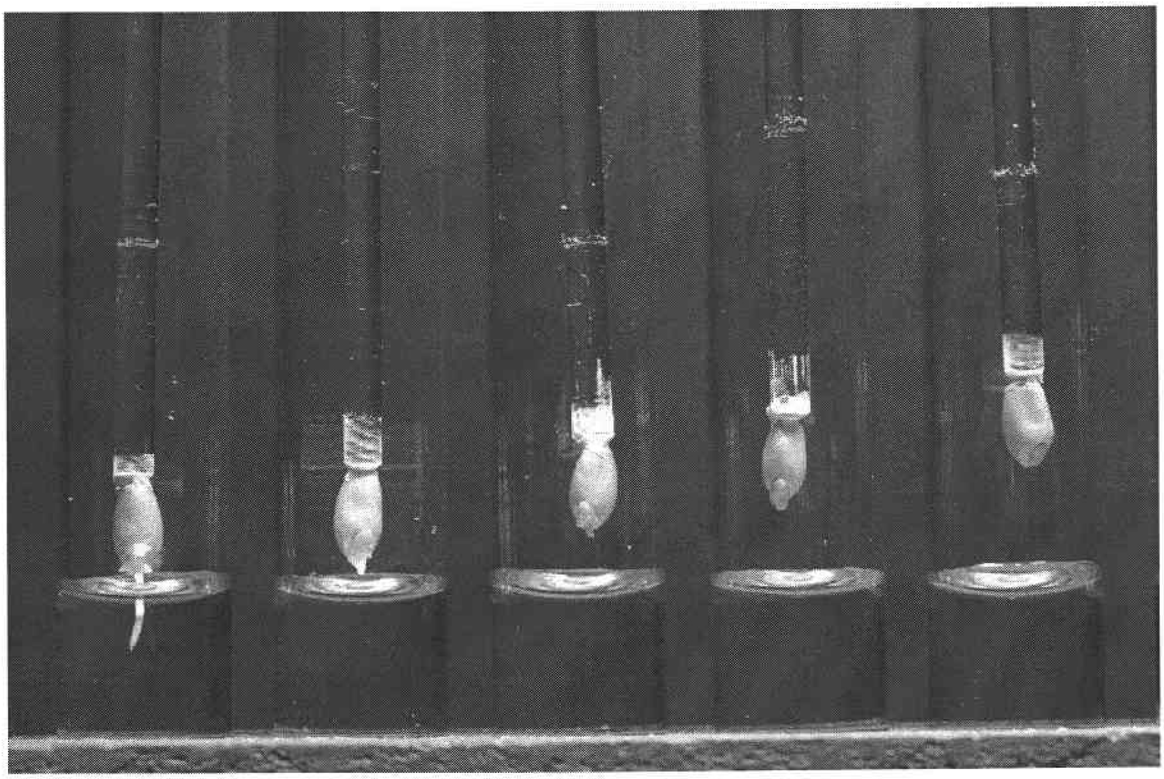
Barley, pea, mustard, and wheat have all been tested for their ability to germinate rapidly with vapor alone. Figure 3 shows



the results of a test where several seeds were placed in petri dishes filled with moist soil. Half the soil surface was covered by fiberglass cloth to prevent seed-soil contact. Seed laid on the fiberglass cloth germinated nearly as fast as seed with good seed-soil contact. (Exactly the same time in the case of mustard, and in this test, faster in the case of barley.) It is also possible to germinate seed in a dry, sealed beaker, if sufficient water vapor is made available (Fig. 4).



The distance that water vapor travels from the liquid source to the seed is critical, as shown in Figure 5. Wheat suspended very close to the water surface in the sealed test tubes germinated in about 3 days. The seed on the right, suspended about one-half inch from the water surface, required about 9 days to germinate. It is surprising to most people that seed can germinate without any contact with liquid water. It is also surprising that a closed vessel with water in the bottom does not have uniform 100 percent relative humidity in the air space above the water surface. These non-intuitive relationships may be why scientists have underestimated the role of vapor in seed germination.



We have yet to precisely measure seed-soil contact, or how to separate liquid flow from vapor flow when both might be contributing to the water absorbed by a seed.

Knowing that vapor is sufficient to quickly germinate seed should help guide future improvements in seeding equipment. Placement at a desirable depth near moist soil is still important, but pressing the seed into firm soil is only helpful if it helps maintain high relative humidity near the seed. Seed should germinate just as quickly in loose moist soil as in firm moist soil, if it has adequate protection from the drying effects of wind and sun.

Acknowledgements

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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
73 Year Average	**.73**	**1.39**	**2.09**	**2.03**	**1.94**	**1.53**	**1.73**	**1.52**	**1.48**	**1.23**	**.35**	**.47**	**16.49**
1982-83	1.68	2.68	1.46	2.69	1.63	2.97	3.90	1.23	2.08	1.92	1.00	.68	23.92
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					
20 Year Average	**.74**	**1.32**	**2.56**	**1.77**	**1.95**	**1.63**	**1.99**	**1.61**	**1.83**	**1.13**	**.36**	**.53**	**17.42**

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
93 Year Average	**.58**	**.93**	**1.70**	**1.62**	**1.62**	**1.17**	**.97**	**.79**	**.83**	**.68**	**.22**	**.28**	**11.37**
1982-83	1.42	1.96	1.08	1.89	1.40	2.43	2.74	.61	1.96	.39	.80	.60	17.28
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					
20 Year Average	**.51**	**.93**	**1.69**	**1.28**	**1.41**	**1.20**	**1.14**	**.90**	**.94**	**.58**	**.30**	**.23**	**11.12**

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
73 Year Average	**78**	**65**	**49**	**42**	**40**	**46**	**54**	**62**	**71**	**79**	**89**	**88**	**115**
1982-83	75	63	44	41	48	52	56	62	72	76	82	88	99
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					
20 Year Average	**78**	**65**	**49**	**40**	**42**	**47**	**55**	**63**	**70**	**78**	**88**	**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
73 Year Average	**43**	**35**	**31**	**27**	**24**	**29**	**32**	**36**	**41**	**47**	**51**	**50**	**-30**
1982-83	44	36	29	29	32	35	37	34	42	47	52	54	18
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					
20 Year Average	**43**	**35**	**32**	**25**	**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
74 Year Average	**75**	**62**	**47**	**39**	**37**	**43**	**51**	**59**	**67**	**74**	**83**	**82**	**111**
1982-83	70	58	42	38	44	45	52	57	68	71	75	81	94
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					
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
74 Year Average	**46**	**37**	**32**	**25**	**26**	**28**	**32**	**37**	**43**	**48**	**54**	**53**	**-24**
1982-83	46	35	27	26	30	32	35	36	43	45	52	55	13
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					
20 Year Average	**48**	**37**	**27**	**16**	**19**	**20**	**32**	**40**	**44**	**50**	**58**	**57**	**-16**