2020

Dryland Field Day Abstracts

Highlights of Research Progress

1

2

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Oregon State University

Washington State University

University of Idaho

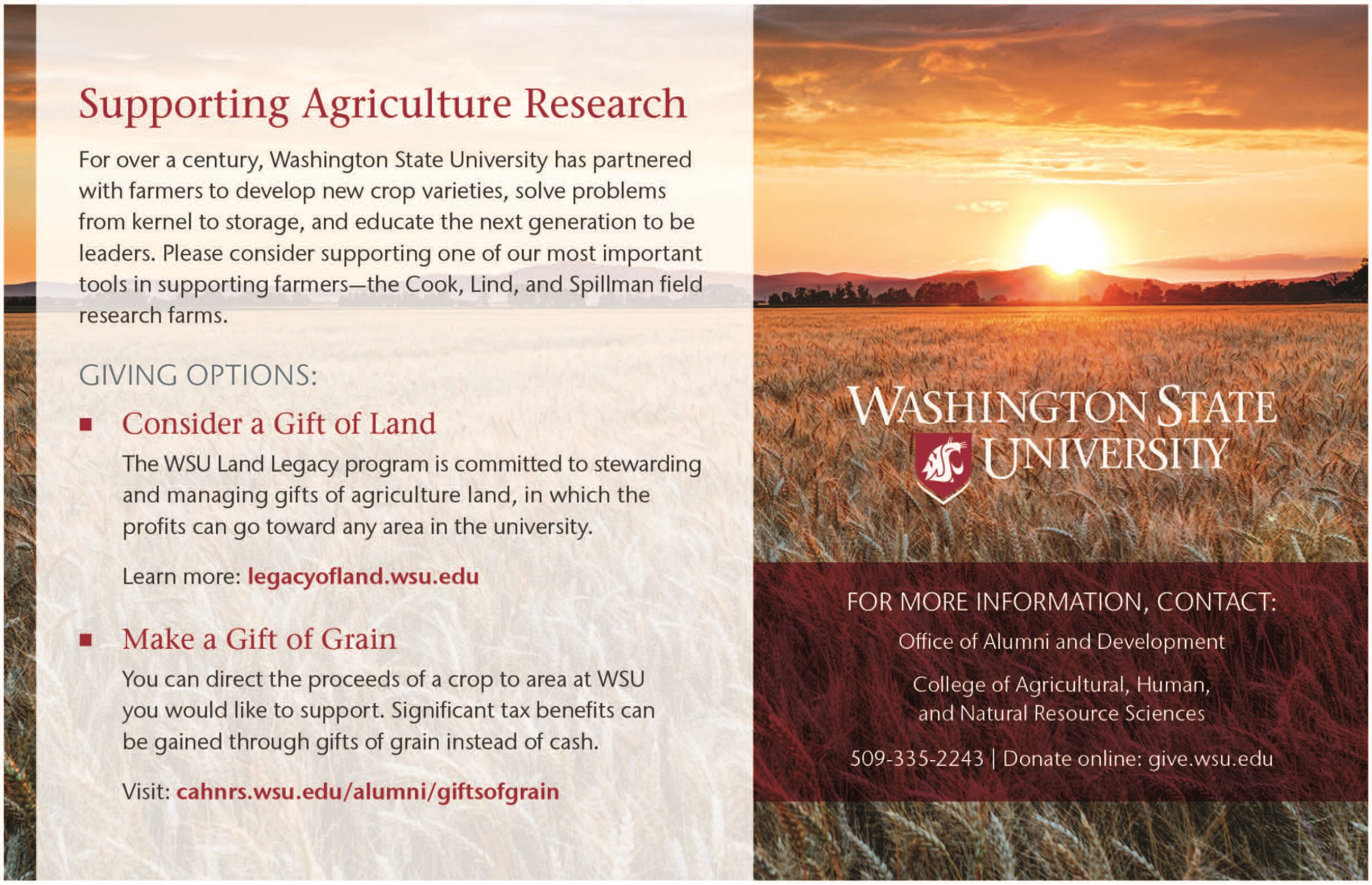

Photo by Karen Sowers

Editors:

WASHINGTON STATE UNIVERSITY
Samantha Crow
Bill Schillinger

UNIVERSITY OF IDAHO
Kurt Schroeder
Doug Finkelnburg
Arash Rashed

OREGON STATE UNIVERSITY
Susan Philips
Mary Corp



Welcome to our 2020 Field Day Abstracts!

2020 Dryland Field Day Abstracts: Highlights of Research Progress

Washington State University
Department of Crop and Soil Sciences
Technical Report 20-1

University of Idaho
Idaho Agricultural Experiment Station
Technical Report UI-2020-1

Oregon State University
Department of Crop and Soil Science
Technical Report OSU-FDR-2020

WOCS
WASHINGTON OILSEED CROPPING SYSTEMS
Part of the Washington State Biofuels Initiative

USDA
United States Department of Agriculture
Agricultural Research Service

PACIFIC NORTHWEST WHEAT-BASED SYSTEMS:
Landscapes in Transition

Table of Contents

Cooperative Personnel and Area of Activity 7

Part 1. Oilseeds and Other Alternative Crops

Washington Oilseed Cropping Systems Extension and Outreach (Madsen and Burke) 13
Effect of Row Spacing and Seeding Rate on Winter Canola Yield in Northern Idaho (Davis et al.) 13
Large Seeded Camelina Breeding Lines with Potential for Public Release (Craine et al.) 15
Spring Canola Large-Scale Variety Trials (Madsen) 16
Plant Density Variation Within Large Scale Variety Trials (Madsen) 17
Pod Count Variation Across Large-Scale Variety Strip Trials (Madsen) 18
Canola Variety Effects on Soil Health Mediated by Nutrients and the Microbiome (Friesen et al.) 20
Managing Nitrogen for Winter Canola (Porter et al.) 20
Understanding the Epidemiology of Blackleg Disease of Canola in Northern Idaho and Eastern Washington (Yearout et al.) 21
Low Erucic Acid (LowE) Camelina Breeding Lines with Potential for Public Release (Craine et al.) 22
Spring Canola and Chickpea Value in a Cereal Grain Rotation (Esser et al.) 23
Soil Water Dynamics with Camelina in a Three-Year Rotation in Washington's Winter Wheat-Fallow Region (Wuest and Schillinger) 24
Developing Diagnosis and Recommendation Integrated System for Micronutrients in Spring Canola (Madsen et al.) 24
Nitrogen Source and Rate to Minimize Damage Caused by Free Ammonia (Madsen and Pan) 26
Use of Transgenic and Agronomic Approaches to Improve Stand Establishment and Survival in Winter Canola (Ahmed and Neff) 26
Mixed Canolage—Companion Cropping of Dual-Purpose Winter Canola (Madsen and VanVleet) 28
Impact of Flea Beetle Damage, Insecticide Application, and Delayed Seeding Dates in Spring Brassica Crops (Davis et al.) 29
Canola in Cereal-Based Rotations: Agronomy and Soil Microbiology Update from Ritzville (Schillinger et al.) 30
A Study to Support Phosphorus Fertility Recommendations for Winter and Spring Canola (Tao et al.) ... 31
Companion Crops as a Method for Improving Winter Canola Stand Establishment and Winter Survival (Madsen and Esser) 32
Single High-Rate Compost Application in Wheat with Winter Pea Rotation: A Long-Term Study (McFarland et al.) 33
Winter Pea: Long-Term Cropping Systems Research in Washington's Drylands (Schillinger et al.) 34

Development of Turf-Type *Poa pratensis* L. Germplasm for Seed Production Without Field Burning and the New Washington State University Grass Breeding and Ecology Farm and Program (Johnston et al.)......35
Winter Triticale: Long-Term Cropping Systems Research in Washington's Wheat-Fallow Drylands (Schillinger et al.)......36
Winter Triticale Does Not Produce More Straw than Winter Wheat (Schillinger et al.) 37
Early versus Late Planting Dates for Winter Triticale and Winter Wheat at Lind (Schillinger et al.) 38

Part 2. Pathology, Weeds, and Insects

Downy Brome Control in Winter Wheat (Campbell and Rauch)......39
Effect of Cultural Management on Russian Thistle Suppression (Genna et al.)......42
Fusarium avenaceum and Soluble Aluminum Induce Defense Protein Release from Wild Oat Seeds (Okubara et al.) 43
Dynamics of Soil Arthropod Communities in Palouse Agroecosystems (Elmquist and Eigenbrode)......43
Population Dynamics of Wheat Root Pathogens Under Different Tillage Systems in NE Oregon (Yin et al.) 44
Wheat Tolerance to Talinor (Campbell and Rauch) 45
Rhizoctonia Infestation and Root Imaging (Doonan and Madsen) 47
Grass and Broadleaf Weed Control in Winter Wheat with Osprey Xtra (Campbell and Rauch)......48
Wheat Soil-Borne Mosaic: Yield Loss and Distribution in the US Pacific Northwest (Kroese et al.) 49
Cereal Rust Management and Research in 2019 (Chen et al.)......50
Wireworm Species Differ in Wheat Plant Damage Under Well-Watered and Drought-Stressed Conditions (Liang et al.)......50
Evaluation of Preemergence Herbicides for the Control of Russian-thistle in Chemical Fallow (Wetzel et al.)......51
How Russian Thistle Germination Changes with Soil Water Potential (Genna and Wuest) 52
Eyespot, Cephalosporium Stripe, and Snow Mold Diseases of Winter Wheat (Murray et al.)......53
Oviposition and Larval Development of the Hessian Fly *Mayetiola destructor* (Diptera: Cecidmyiidae) on Different Host Plants (Sadeghi et al.)......54

Part 3. Breeding, Genetic Improvement, and Variety Evaluation

OSU Cereal Extension Program Updates (Graebner et al.) 55
Washington State University Extension Cereal Variety Testing Program (Neely et al.)......55

Winter Wheat Breeding and Genetics at WSU (Carter et al.)... 56
Two Soft White Winter Wheat Cultivars — VI Bulldog and VI Frost (Wang and Kalous) 57
Developing an Immunoassay for Late Maturity a-amylase (LMA) and Preharvest Sprouting (PHS) (Hauvermale et al.)... 57
Exploring *CAD* Genes as Agents for Stress-Tolerant Wheat (Peracchi et al.) 58
Charactering the Genetics of LMA in North American Spring Wheat (Liu et al.) 60
Picture This: Using a Bird's-Eye View to Improve Genetic Gain in a Winter Breeding Program (Herr and Carter) 61
Analysis of *SALP1* Genes in Wheat for Stress Tolerance (Brew-Appiah and Sanguinet) 62
Genomic Selection of Stripe Rust Resistance in a Wheat Breeding Program (Merrick et al.)................... 64
Developing a Phenomics Program for Plant Biology Utilizing Two Automated Phenomics Platforms (Bellinger et al.) 65
Integrating Spectral Information and Genomic Selection for Predicting Grain Protein Content in Wheat (Sandhu et al.) 66
The USDA-ARS Western Wheat Quality Laboratory (Morris et al.) 66
Low Falling Number Problems May Result from Vivipary, the Germination of Immature Wheat Grain (Peery et al.) 67
Mapping of Genes/Loci Controlling Preharvest Sprouting and Emergence in Northwest Wheat (Wigen et al.) 68
Genomic Selection of Seedling Emergence in a Wheat Breeding Program (Merrick et al.)...................... 70

Part 4. Agronomy and Soils

Do Soil Microbes Contribute to Wheat Yield and Soil Health? (Schlatter et al.) 71
Timing of Cover Crop Termination (Baskota and Schroeder).. 71
The WSU Wilke Research and Extension Farm Long-Term Rotation Summary (Esser and Appel) 73
Nitrogen Stabilizers to Improve Nitrogen Use Efficiency in Winter Wheat in High Rainfall Zones of Northern Idaho (Seubert et al.)... 73
Wheat Stubble Height Effects on Soil Water Capture and Retention During Long Fallow (Schillinger et al.)... 74
Agroecological Advantages of Early-Sown Winter Wheat in Semi-Arid Environments: A Comparative Case Study from Southern Australia and Pacific Northwest USA (Cann et al.) 76

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Washington State University
Cooperative Personnel and Area of Activity

Kirk H. Schulz	President, Washington State University
André-Denis Wright	Dean of College of Agricultural, Human, and Natural Resource Sciences
Richard T. Koenig	Chair, Department of Crop & Soil Sciences
Scot H. Hulbert	Associate Dean for Research and Director, Agricultural Research Center
Vicki McCracken	Associate Dean and Director of Extension
Richard S. Zach	Associate Dean, Academic Programs

Agronomy, Conservation Systems, Soil Fertility, and Oilseeds

D. Brown	509-335-1859	dave.brown@wsu.edu
P. Carter	509-382-4741	cart@wsu.edu
D. Crowder	509-335-7965	dcrowder@wsu.edu
A. Esser	509-659-3210	aarons@wsu.edu
S. Fransen	509-786-9266	fransen@wsu.edu
D. Huggins, USDA	509-335-3379	dhuggins@wsu.edu
R.T. Koenig	509-335-2726	richk@wsu.edu
D. Llewellyn	509-735-3551	don.llewellyn@wsu.edu
I. Madsen	360-448-9081	isaac_madsen@wsu.edu
C. Neely	509-335-1205	clark.neely@wsu.edu
H. Neely	509-335-0947	h.neely@wsu.edu
M.M. Neff	509-335-7705	mmneff@wsu.edu
W.L. Pan	509-335-3611	wlpan@wsu.edu
W.F. Schillinger	509-235-1933	william.schillinger@wsu.edu
H. Tao	509-335-4389	haiying.tao@wsu.edu
D. Whaley	509-745-8531	dwhaley@wsu.edu

D. Appel, B. Barry, J. Braden, K. Curran, B. Gerrish, C. Hoffman, J. Jacobsen, J. Morse, E. Reardon, R, Rupp, S. Schofstoll, R. Sloot, E. Warner

Breeding, Variety Testing, and Culture of Legumes

Dry Peas, Lentils, Chickpeas

R. McGee, USDA	509-335-0300	rebecca.mcgee@usda.gov
G. Vandemark, USDA	509-335-7728	george.vandemark@usda.gov

T. Chen, J. Haines, M. Lauver, S.L. McGrew, J. Pfaff, N. Pierre-Pierre

Dry Beans

P. Miklas, USDA	509-786-9258	phil.miklas@usda.gov

T. Anderson, S. Swanson

Cereal Breeding, Genetics, and Physiology

Wheat Breeding & Genetics

K. Garland-Campbell, USDA	509-335-0582	kim.garland-campbell@usda.gov
A.H. Carter	509-335-6198	ahcarter@wsu.edu
K.S. Gill	509-335-4666	ksgill@wsu.edu
S.S. Jones	360-416-5210	joness@wsu.edu
C.F. Morris, USDA	509-335-4062	craig.morris@usda.gov
M.M. Neff	509-335-7705	mmneff@wsu.edu
M.O. Pumphrey	509-335-0509	m.pumphrey@wsu.edu
K. Sanguinet	509-335-3662	karen.sanguinet@wsu.edu
D.R. See, USDA	509-335-3632	deven.see@wsu.edu
C. Steber, USDA	509-335-2887	camille.steber@usda.gov

K. Balow, B. Bellinger, R. Brew-Appiah, A. Burke, J. DeMacon, P. DeMacon, V.L. DeMacon, K. Hagemeyer, T. Harris, V. Jitkov, E. Klarquist, S. Lyon, W. Nyongesa, S. Rynearson, G.B. Shelton, R. Sloot, A. Stowe, N. Wen, J. Worapong

Barley Breeding & Genetics

B. Brueggeman	509-335-5272	bob.brueggeman@wsu.edu

M. Wood

Crop Diseases

Cephalosporium Stripe, Foot Rots, Snow Molds, and Virus Diseases

T.D. Murray	509-335-7515	tim.murray@wsu.edu

H. Sheng

Wheat Health

P. Okubara, USDA	509-335-7824	patricia.okubara@usda.gov
T. Paulitz, USDA	509-335-7077	timothy.paulitz@usda.gov
L. Thomashow, USDA	509-335-0930	linda.thomashow@usda.gov
D. Weller, USDA	509-335-6210	david.weller@usda.gov

Rusts, Smuts; Foliar, Virus and Bacterial Diseases

L. Carris	509-335-3733	carris@wsu.edu
W. Chen, USDA	509-335-9178	weidong.chen@usda.gov
X.M. Chen, USDA	509-335-8086	xianming.chen@usda.gov
C.K. Evans, USDA	509-335-8715	kent.evans@usda.gov
Y. Liu	509-335-1596	y.liu@wsu.edu
J. Sprott, USDA	509-335-4789	jason.sprott@usda.gov
M.N. Wang	509-335-1596	meinan_wang@wsu.edu

Soil Microbiology

L. Carpenter-Boggs	509-335-1533	lcboggs@wsu.edu
M. Friesen	509-335-5805	m.friesen@wsu.edu
J.C. Hansen, USDA	509-335-7028	jeremy.hansen@usda.gov
T. Sullivan	509-335-4837	t.sullivan@wsu.edu

Weed Management

I.C. Burke	509-335-2858	icburke@wsu.edu
D.J. Lyon	509-335-2961	drew.lyon@wsu.edu

D. Appel, R. Sloot, M. Thorne, H. Wetzel

Wheat Quality and Variety Evaluation

Wheat Quality

C.F. Morris, USDA	509-335-4062	craig.morris@usda.gov

M.L. Baldridge, D. Bolingbroke, S. Conrad, D.A. Engle, U. Ganjyal, W.J. Kelley, A.M. Kiszonas, S. Lenssen, K. Leonard, J. Luna, G. Mikhaylenko, C. Munoz, N. Ovetz, G.L. Peden, D. Power, M. Rauch, R. Saam, E. Stout, S. Sykes, Y. Thompson, S. Vogl, E. Wegner

WSU Extension Cereal Variety Testing

C. Neely	509-335-1205	clark.neely@wsu.edu

B. Gerrish, A. Horton

WSCIA Foundation Seed Service & Certification

G. Becker	509-335-4365	
D. Hilkin	509-335-4365	darlene@washingtoncrop.com
D. Krause	509-335-4365	darryl@washingtoncrop.com
K. Olstad	509-334-0461	karen@washingtoncrop.com
L. Port	509-334-0461	lauren@washingtoncrop.com
H. Sweet	509-334-0461	hannah@washingtoncrop.com

Field Stations

WSU Lind Dryland Research Station		
B.E. Sauer, Farm Manager	509-677-3671	sauerbe@wsu.edu
WSU Plant Pathology Farm		
F. Ankerson, Farm Manager	509-335-3081	fca@wsu.edu
WSU Spillman Farm and WSU Cook Farm		
F. Ankerson, Farm Manager	509-335-3081	fca@wsu.edu
WSU/USDA-ARS Palouse Conservation Field Station		
F. Ankerson, Farm Manager	509-335-3081	fca@wsu.edu
WSU Wilke Farm		
A. Esser, Adams Co. Director	509-659-3210	aarons@wsu.edu

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University of Idaho
Cooperative Personnel and Area of Activity

C. Scott Green	President, University of Idaho
Michael P. Parrella	Dean, College of Agricultural and Life Sciences
Mark McGuire	Associate Dean of Research & Director of Idaho Agricultural Experiment Station
Barbara Petty	Associate Dean & Director of Extension

Agronomy and Cropping Systems

D. Finkelnburg	208-799-3096	dougf@uidaho.edu
X. Liang	208-397-7000 x110	xliang@uidaho.edu
J. Marshall	208-529-8376	jmarshall@uidaho.edu
N. Olsen	208-423-6634	norao@uidaho.edu
K. Schroeder	208-885-5020	kschroeder@uidaho.edu
G. Shewmaker	208-423-6678	gshew@uidaho.edu
R. Spear	208-397-7000	rhetts@uidaho.edu
M. Thornton	208-722-6701 x211	miket@uidaho.edu
O. Walsh	208-722-6701 x218	owalsh@uidaho.edu

K. Beck, J. Davis, C. Jackson, L. Jones, C. Lowder, J. McClintick, K. O'Brien, M. Moll, R. Portenier, C. Poulson, R. Roemer, L. Schroeder, T. Shelman, L. Woodell, W. Zhao

Cereal Breeding, Genetics, and Variety Testing

J. Chen	208-397-4162 x229	jchen@uidaho.edu
D. Fu	208-885-1542	dlfu@uidaho.edu
J. Marshall	208-529-8376	jmarshall@uidaho.edu
K. Schroeder	208-885-5020	kschroeder@uidaho.edu
Y. Wang	208-885-9110	ywang@uidaho.edu

J. Davis, C. Jackson, N. Klassen, L. Jones, R. Lawrence, K. O'Brien, J. Wheeler, B. Yimer, W. Zhao

Crop Diseases

L-M. Dandurand	208-885-6080	lmd@uidaho.edu
K. Duellman	208-529-8376	kduellman@uidaho.edu
A. Karasev	208-885-2350	akarasev@uidaho.edu
J. Kuhl	208-885-7123	jkuhl@uidaho.edu
J. Marshall	208-529-8376	jmarshall@uidaho.edu
B. Schroeder	208-339-5230	bschroeder@uidaho.edu
K. Schroeder	208-885-5020	kschroeder@uidaho.edu
P. Wharton	208-397-7000 x108	pwharton@uidaho.edu
J. Woodhall	208-722-6701	jwoodhall@uidaho.edu

B. Amiri, A. Bates, W. Bills, J. Chojnacky, J. Dahan, K. Fairchild, A. Gray, M. Harrington, M. Haylett, C. Jackson, L. Jones, S. Keith, A. Kud, M. Lent, A. Malek, M. Murdock, G. Orellana, C. Pizolotto, A. Poplawsky, J. Randall, S. Sivasankara Pillai, B. Yimer

Integrated Pest Management

J. Clements	208-722-6701	justineclements@uidaho.edu
S. Eigenbrode	208-885-2972	sanforde@uidaho.edu
S. Hafez	208-722-6701 x237	shafez@uidaho.edu
A. Rashed	208-397-7000 x114	arashed@uidaho.edu
M. Schwarzläender	208-885-9319	markschw@uidaho.edu
E. Wenninger	208-423-6677	erik@uidaho.edu

S. Adhikari, D. Carmona, F. Garcia, B. Harmon, S. Odubiyi, L. Standley, A. Stanzak, Y. Wu

Soil Fertility and Management

J. Johnson-Maynard	208-885-9245	jmaynard@uidaho.edu
R. Mahler	208-885-7025	bmahler@uidaho.edu
I. Popova	208-885-4953	ipopova@uidaho.edu
D. Strawn	208-885-2713	dgstrawn@uidaho.edu
O. Walsh	208-722-6701 x218	owalsh@uidaho.edu

A. Crump, K. Kahl, J. McClintick

Weed Management

J. Campbell	208-885-7730	jcampbel@uidaho.edu
P. Hutchinson	208-397-7000 x109	phutch@uidaho.edu
T. Prather	208-885-9246	tprather@uidaho.edu

B. Beutler, L. Jones, T. Keeth, B. Kendall, C. Miera, T. Rauch

Field Stations

UI PARKER FARM

R. Patten, Farm Manager	208-885-3276	royp@uidaho.edu

UI KAMBITSCH FARM

B. Bull, On-site Ag Mechanic	208-885-3276	bbull@uidaho.edu

Photo by Sarah Seubert

Oregon State University
Cooperative Personnel and Area of Activity

Edward J. Ray	President, Oregon State University
Alan Sams	Dean of the College of Agricultural Sciences
Staci Simonich	Executive Associate Dean
Dan Edge	Associate Dean and Associate Director
Joyce Loper	Associate Dean of Research
Tom Chastain	Department of Crop and Soil Sciences
Mary Corp	Director, Columbia Basin Agricultural Research Center

Agronomy

D. Long, USDA (retired)	541-969-6122	dan.long@usda.gov
S. Machado	541-278-4416	stephen.machado@oregonstate.edu

L. Pritchett

Barley Breeding

P. Hayes	541-737-5878	patrick.m.hayes@oregonstate.edu

Wheat Breeding

K. Garland Campbell	208-310-9876	kim.garland-campbell@usda.gov
R. Zemetra	541-737-4278	robert.zemetra@oregonstate.edu

Chemistry—Wheat

A. Ross	541-737-9149	andrew.ross@oregonstate.edu

Extension

R. Graebner	541-278-4186	graebner@oregonstate.edu
L. Lutcher	541-676-9642	larry.lutcher@oregonstate.edu
J. Maley	541-384-2271	jordan.maley@oregonstate.edu
D. Walenta	541-963-1010	darrin.walenta@oregonstate.edu
D. Wysocki	541-969-2014	dwysocki@oregonstate.edu

M. Hunt, D. Rudometkin Odell, A. Wernsing

Soil Microbiology

D. Myrold	541-737-5737	david.myrold@oregonstate.edu
C. Reardon, USDA	541-278-4392	catherine.reardon@usda.gov

Soil Science

H. Gollany, USDA	541-278-4410	hero.gollany@usda.gov
J. Williams, USDA	541-278-4412	john.d.williams@usda.gov
S. Wuest, USDA	541-278-4381	stewart.wuest@usda.gov

Plant Pathology

C. Hagerty	541-278-4396	christina.hagerty@oregonstate.edu
C. Mundt	541-737-5256	mundtc@science.oregonstate.edu
R. Smiley, Emeritus Prof.	541-278-4397	richard.smiley@oregonstate.edu

D. Kroese

Weed Management

D. Ball, Emeritus Professor	541-354-1261	daniel.ball@oregonstate.edu
J. Barroso	541-278-4394	judit.barroso@oregonstate.edu

N. Genna, J. Gourlie

Part 1. Oilseeds and Other Alternative Crops

Washington Oilseed Cropping Systems Extension and Outreach

Isaac J. Madsen and Ian Burke
Dept. of Crop and Soil Sciences, WSU

The Washington Oilseed Cropping System (WOCS) project focuses on conducting research and extension to improve oilseed production in Washington state. Over the past 13 years the WOCS project has conducted research on safflower, sunflowers, flax, camelina, and canola. The WOCS research program has focused a range of research areas including but not limited to fertility, herbicide use, plant density, and planting date. Effectively disseminating the information generated from this research is also in the purview of the WOCS project. The year 2019 saw some major changes in the WOCS extension staff. Karen Sowers moved on to work as the executive director for the Pacific Northwest Canola Association. While we were sad to have Karen leave the team, we are excited that she will continue to be involved in canola production and outreach in the region. Following Karen's departure, a new position for an extension agronomist in oilseeds was opened in the Department of Crop and Soil Sciences at Washington State University. The extension agronomist position expanded on the extension responsibilities of previous extension position and included both research and teaching appointments within the Department of Crop and Soil Sciences. In September of 2019, Isaac Madsen was appointed as the extension agronomist for the WOCS project. During the 2019 field season the extension team successfully hosted "stop and talks" and large-scale variety trials. The large-scale field variety trials were featured in the Pullman Weed Science and the Wilke Farm Field Days. In February of 2020, the extension team hosted the annual winter workshops in Wilbur and Clarkston. Attendance for the winter workshops was down from 253 in 2019 to 141 in 2020. However, we are looking forward to increased attendance in 2021! In addition to the traditional outreach activities of field days and workshops we continue to utilize podcasts, websites, and social media to spread the most recent information on canola production in Washington state. The WOCS website (www.css.wsu.edu/oilseeds) functions as the primary storehouse of the research conducted on oilseeds as part of the WOCS. The WOCS Facebook page (https://www.facebook.com/WSUOilseeds/) also continues to be active as a platform for disseminating information on upcoming events and any interesting observations we encounter while we are out and about the countryside. Additionally, Drew Lyon of the Wheat & Small Grains extension team was kind enough to host two canola centric interviews on The WSU Wheat Beat Podcast. Finally, 2020 has been an odd year to conduct research with social distancing in place please keep an eye out for video recording discussing the current research and extension efforts being conducted on oilseeds at WSU.

Effect of Row Spacing and Seeding Rate on Winter Canola Yield in Northern Idaho

Jim B. Davis, Eric Ireton, Megan Wingerson, Ashley Job, and Jack Brown
Dept. of Plant Sciences, UI

This study examined the effect of row spacing on seed yield and fall forage or biomass production and was initiated in the summer of 2014 at two sites near Moscow and Genesee, Idaho. The study was repeated for four years with harvests occurring each year from 2015 to 2018. Trials were seeded at two dates each year; an early seeding date in mid to late July and a traditional late seeding date in mid to late August or early September, depending on the year.

Row spacings of 10 and 20 inches and seeding rates of 3.2 and 4.8 lbs. per acre (approximately 285,000 and 425,0000 seeds per acre) were examined with four cultivars; 'Amanda,' 'HyCLASS 125W RR,' 'Mercedes' (except 2014-15), and a UI breeding line 'UI.WC.15.7.5.' The trials were planted on tilled fallow using a plot drill with Flexicoil paired-row Stealth openers. Fertilizer was pre-plant incorporated.

Plant biomass was estimated at the Moscow early sites in late September 2015, 2016, and 2017 by cutting, drying, and weighing a quadrat of foliage from each plot. When the plants were mature the following year, each plot was cut with a plot swather to ease harvest. When the swathed plants were dry, each plot was threshed with a small plot combine. The seed was dried to a uniform moisture content and weighed to determine yield. The 2015 Moscow late site was lost to winter kill, and the 2016 Genesee early and both 2018 Genesee dates did not establish due to dry soil conditions at seeding. A total of 12 trials were evaluated for seed yield over the course of the study.

As expected, the cultivars used in the trial produced different seed yields (Table 1). No significant interactions were found between cultivars and the other treatments, indicating that all four cultivars responded the same to the seeding rate and row spacing treatments. Neither row spacing nor seeding rate affected seed yield when averaged over the 12 site-date-years and the four cultivars. (Tables 2 and 3). Fall biomass production was not significantly impacted by seeding rate; although a trend (p=0.10) for higher biomass was seen with the narrow spacing as compared to the wide row spacing. No significant interactions were found between row spacing and the other factors.

Table 1. Mean seed yield and fall biomass of four winter canola cultivars averaged across two seeding rates and two row spacings. Seed yield is from nine site-date-years and fall biomass is from three site-date-years.

Cultivars	Fall Biomass (*lbs./acre*)	Seed Yield (*lbs./acre*)
Mercedes	4,826	4,265 ^{a}
Amanda	4,734	3,803 ^{b}
UI.WC.1.5.7.5	4,734	3,809 ^{b}
HyCLASS 125W RR	4,385	3,643 ^{c}
LSD (p=0.05)	n.s.	128

Means within columns with different superscript letters are significantly different (*P*<0.05)

At the 2015 Moscow early site, the narrow row spacing resulted in a higher yield by 402 lbs. per acre, but the wide row spacing resulted in higher yields at the 2016 Moscow late site and the 2018 Moscow early site by 708 and 151 lbs. per acre, respectively. At the 2016 Genesee late site, the lower seeding rate increased seed yield by 275 lbs. per acre, but at the 2016 Moscow early site and the 2018 Moscow late site, the high seeding rate increased seed yield by 248 and 154 lbs. per acre, respectively.

Table 2. Mean seed yield and fall biomass of narrow and wide row spacing averaged across four winter canola cultivars. Seed yield is from 12 site-date-years and fall biomass is from three site-date-years.

Row Spacing	Fall Biomass (*lbs./acre*)	Seed Yield (*lbs./acre*)
10-inch	4,862	3,584
20-inch	4,478	3,575
LSD (p=0.05)	n.s.	n.s.

While the seeding rates and row spacings examined in this study did occasionally affect yield at some sites in some years, no pattern was discernable, and growers should be successful with a variety of seeding rates and row spacings within the ranges examined in this study. The lack of differences in yield when averaged across all site-years indicates that growers can produce winter canola using a variety of row spacings without compromising the yield potential of their crops.

Table 3. Mean seed yield and fall biomass of low and high seeding rates averaged across four winter canola cultivars. Seed yield is from 12 site-date-years and fall biomass is from three site-date-years.

Seeding Rate	Fall Biomass (*lbs./acre*)	Seed Yield (*lbs./acre*)
Low	4,706	3,543
High	4,635	3,615
LSD (p=0.05)	n.s.	n.s.

Large Seeded Camelina Breeding Lines with Potential for Public Release

Wilson A. Craine[1], Ian C. Burke[1], Philip D. Bates[2], and Scot H. Hulbert[1]
[1]Dept. of Crop and Soil Sciences, WSU; [2]Institute of Biological Chemistry, WSU

Camelina is a potential alternative crop for the sustainable intensification off dryland cropping systems, especially in the inland Pacific Northwest (iPNW). Despite minimal input requirements, strong adaptability to diverse environmental conditions and a "heart-healthy" fatty acid profile suitable for biodiesel and renewable jet fuel production, weed control is a big hindrance to the adoption of camelina into iPNW wheat rotations. Small seed size necessitates shallow planting and impacts germination in dryer soils, preventing good stand establishment and enabling weeds to establish significant populations. Additionally, very few herbicides labeled for use on camelina drastically limits options for controlling weeds once they establish. Development of larger seeded camelina varieties will boost germination and stand establishment, decreasing weed pressure.

The WSU Camelina Breeding program has developed several elite large seeded camelina breeding lines that also exhibit good agronomic performance. During the 2019 field season, 12 advanced large seeded breeding lines and 6 check varieties were tested in a replicated field trial in Pullman, WA. There were two seeding dates, May 10 and May 23, and at least four replicated plots (5ft x 9ft) of each genotype (16 for Calena and Suneson) per seeding date, arranged in a randomized complete block design (RCBD). Overall, the lines performed similarly in both seeding dates, so only means across seeding dates for each line is given.

Table 1 details the performance of each large seed line and check variety, sorted from largest to smallest single seed mass (1SM). Every large seeded line has significantly higher oil content and is significantly bigger than the check varieties, but there were no significant differences in 1SM or oil content within large seeded lines. Line #31 is promising, with the highest yield and high oil content. However, more environments/years are necessary to determine the top performing large seeded line(s). Fortunately, these large seeded lines were grown in single-location, replicated field trials in each of the 2017, 2018 field seasons. Seed samples from those field seasons have yet to be analyzed for oil content and fatty acid composition, but we do have yield and 1SM data for those lines.

Table 1. Grouped means for all Large Seed Breeding Lines + Check Varieties. Lowercase letters denote significant differences (Tukey HSD) between means; "r" is the number of replicates per genotype.

r	Genotype	Yield (lbs/acre)	1SM (mg)	Oil (%)	Linoleic (%)	α-Linolenic (%)	Erucic (%)
8	LargeSeed.23	1064.5a	1.83a	40.53ab	20.48ab	32.37ab	2.82bcd
8	LargeSeed.28	1028.9a	1.81a	39.02abcd	19.66bc	32.66ab	3.01abc
8	LargeSeed.26	1158.1a	1.81a	39.96abc	19.72bc	33.11ab	3.03abc
8	LargeSeed.30	1074.7a	1.78a	39.74abc	18.89bc	33.69a	3.14abc
8	LargeSeed.24	1134.1a	1.78a	40.53ab	20.14abc	32.51ab	2.92abc
8	LargeSeed.21	909.5a	1.77a	40.72a	20.55ab	31.98ab	2.82bcd
8	LargeSeed.22	1186.8a	1.76a	40.79a	19.49bc	32.88ab	2.91abc
8	LargeSeed.25	1144.5a	1.74a	39.97abc	19.58bc	32.87ab	3.17ab
8	LargeSeed.31	1271.7a	1.71a	40.04abc	19.78bc	32.19ab	3.21ab
8	LargeSeed.20	945.3a	1.70a	38.89abcd	20.01abc	31.65ab	3.21ab
8	LargeSeed.29	1163.1a	1.69a	39.58abc	19.97abc	32.30ab	3.24ab
8	LargeSeed.27	1114.8a	1.68a	40.15abc	20.01abc	32.90ab	3.34a
8	Cheyenne	1142.6a	1.33b	33.51d	18.37c	31.86ab	2.93abc
8	Midas	917.8a	1.32b	35.41cd	19.59bc	33.35ab	2.80bcd
32	Calena	1133.5a	1.28b	35.62cd	19.54bc	33.35ab	3.01abc
8	BlaineCreek	999.7a	1.26b	35.10cd	18.89bc	32.96ab	2.64cd
8	WA-HT1	1060.4a	1.24b	35.99bcd	19.06bc	33.57a	2.78bcd
32	Suneson	1072.7a	1.24b	36.04bcd	21.29a	31.37b	2.44d

Table 2 depicts the grouped means for all large seeded breeding lines across the 2017, 2018, and 2019 seasons. Overall, the lines seem to perform similarly across all years as they did in 2019. Line #31 stands out with second highest yield across three years. The addition of oil content and fatty acid composition data for 2017 and 2018 will help us identify the best large seed line(s) for release, hopefully in fall 2020.

*Note: The WSU Camelina Breeding Program released WA-HT1, a group II soil herbicide resistant variety, in 2018. All of these large seeded lines have that herbicide tolerant trait and exhibit resistance to soil residual levels of group II herbicides.

Table 2. Grouped means for all Large Seed Breeding Lines across 2017, 2018, and 2019 seasons. There were no significant differences (Tukey HSD) between any means; "r' is the number of replicates per genotype.

r	Genotype	Yield (lbs/acre)	1SM (mg)
13	LargeSeed.24	933.6	1.67
14	LargeSeed.23	895.1	1.67
14	LargeSeed.30	915.4	1.66
14	LargeSeed.28	863.5	1.65
14	LargeSeed.26	975.1	1.65
14	LargeSeed.25	1028.9	1.64
14	LargeSeed.21	803.7	1.63
13	LargeSeed.22	959.6	1.61
14	LargeSeed.31	1015.4	1.60
14	LargeSeed.29	968.4	1.59
14	LargeSeed.27	927.8	1.57
14	LargeSeed.20	804.4	1.57

Spring Canola Large-Scale Variety Trials

ISAAC J. MADSEN
DEPT. OF CROP AND SOIL SCIENCES, WSU

Small plot variety trials serve to assess the relative yields and traits of varieties. However, small plots do not capture the effect of landscape on different varieties. In order to assess the effect of landscape on yield and other important agronomic variables it is important to test varieties on a larger scale (Fig. 1). The large-scale variety trials are planted with a production scale drill and range from 400-600 ft in length. Each variety was replicated four times to allow for statistical comparisons of yield, nutrient concentration, and stand counts. During the 2019 growing season, large-scale variety trials were conducted at three locations. The varieties at each location varied based on what is commonly grown in each region. The variety trial locations were at Almira, WA, Davenport, WA, and Pullman, WA. At the Almira location, all the varieties except InVigor L233P were non-GMO. At the Davenport location a mix of non-GMO and GMO varieties were planted. At the Pullman location only RoundUp Ready varieties were planted. At both Almira and Davenport there were significant differences based on variety (Table 1). However, at Pullman, there was no significant differences based on yield. At the Davenport location NCC101S had the

Figure 1. Strip trials near Pullman, WA demonstrate the landscape variability which can be captured with large scale trials.

highest yield, while at Almira InVigor L233P had the highest yield. In addition to yield plant count, pod count, and nutrient concentration data were collected. Each of these data was spatially referenced in order to assess the variability across the field.

Table 1

		Almira		Davenport		Pullman
BY5545 CL		854 b		1117 d	-	-
DynaGrow DG200CL		854 b		1259 bcd	-	-
InVigor L233P		947 a		1217 cd	-	-
NCC101S		819 b		1678 a	-	-
Xceed DG X122 CL		781 b	-	-	-	-
BrettYoung 6080 RR	-	-		1120 d		1741 a
DynaGrow DG540 RR	-	-		1200 cd		1697 a
HyClass 930 RR	-	-		1445 b		1680 a
Star 402 RR	-	-		1369 bc		1730 a
Mean		851		1301		1712
CV (%)		7.0		11.9		26.2
LSD		90		227		692

Plant Density Variation Within Large Scale Variety Trials

ISAAC J. MADSEN
DEPT. OF CROP AND SOIL SCIENCES, WSU

In addition to collecting yield data, large-scale variety trials can be utilized to collect a variety of other data including plant density. During the summer of 2019 plant counts were collected at all three of the large-scale variety trial locations. Because the plot length and width varied at each location depending on the drill being used, and the size and shape of the field which the trials were established in, each location had a slightly different sampling scheme. In Almira (plot size 40’ x 600’) four plant counts were taken for times at 120’ beginning 60’ into the plot. Similarly, in Pullman (plot size 30’x 500’) four plant counts were taken four times at 100’ intervals resulting 16 counts per plot beginning 50’ into the plot. However, at Davenport (plot size 15’x 400’) four plant counts were only taken three times at 100’ intervals resulting in 12 counts per plot. In total, 320, 256, and 384 plant counts were collected at Almira, Pullman, and Davenport respectively. The number of plants ft-2 varied greatly between location. The highest and the lowest plant counts were found at Davenport ranging from 0.0-15.6 plants ft-2. Pullman plant counts varied to a lesser degree from 1.1-9.3 plants ft-2. At Almira the plant counts ranged from 1.9-13.4 plants ft-2. The plant counts were aggregated to

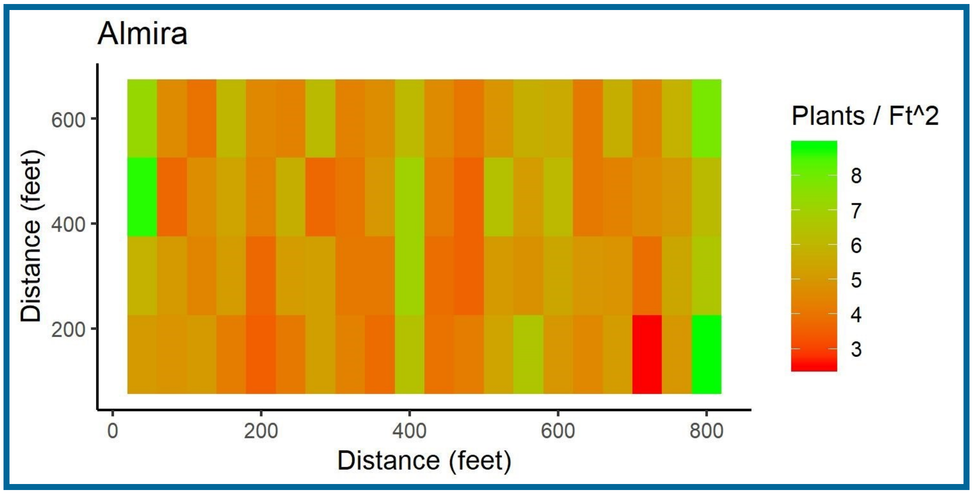

Figure 1. Aggregated plant counts varied from 2.5-8.8 plants per square foot at Davenport, WA.

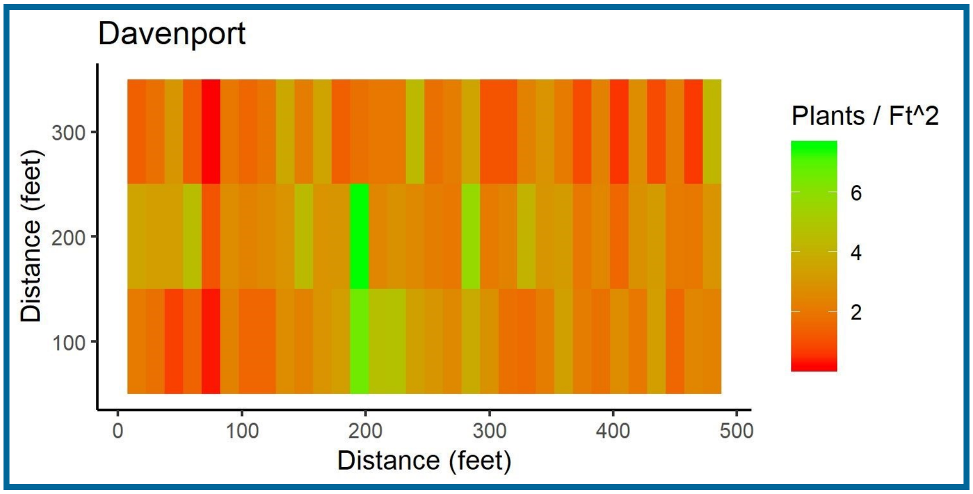

Figure 2. Aggregated plant counts varied from 0.7-7.5 plants per square foot at Davenport, WA.

four counts per plot and mapped to the plots using R statistical software (Fig. 1-3). The maps of plant counts demonstrate the large range of range of variability across a single field. However, when compared to yield on a plot by plot basis the plant counts did not predict yield within a single location or between any of the locations (Fig. 4). The lack of correlation between plant density and yield demonstrates, high plant densities are not necessarily required for good yields. However, benefits such as competition against weeds may be gained through higher plant density. Future work will focus on linking the yield monitor data from these locations to the plant count data in order to look at relations between plant count and yield at a higher spatial resolution.

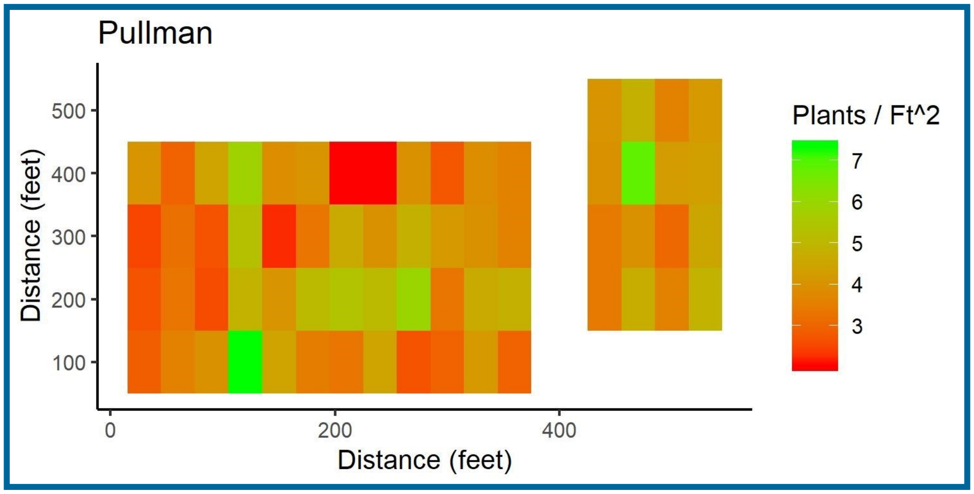

Figure 3. Aggregated plant counts varied from 2.0-7.3 plants per square foot at Davenport, WA.

Pod Count Variation Across Large-Scale Variety Strip Trials

ISAAC J. MADSEN
DEPT. OF CROP AND SOIL SCIENCES, WSU

In addition to collecting yield data, large-scale variety trials can be utilized to collect a variety of other data including pod counts. The pod count on the leading stem of a canola plant has been anecdotally correlated with yield. In this project we set out to assess the possible correlations between pod count and yield data. When the plants were at physiological maturity pod counts were taken at 16 points within each plot (Fig. 1). Of the 8 varieties grown at Davenport and the 5 varieties planted at Almira, there were four shared varieties. A comparison of the shared varieties across both locations showed that Davenport averaged a higher pod count (39) than Almira (32). In Almira, the pod counts varied from 13 -53 pods and at Davenport the pod count ranged from 12-60. The average yield in Almira was 851 lbs/A and the average yield in Davenport was 1301 lbs/A. Although a strong correlation between pod count and yield was not achieved when conducting linear regression (R2=0.43), a positive trend between pod count and yield was observed. At neither location did the highest yielding variety (NCC101s at Davenport and InVigor L233P at Almira) have the highest number of pods. The total number of pod counts collected at

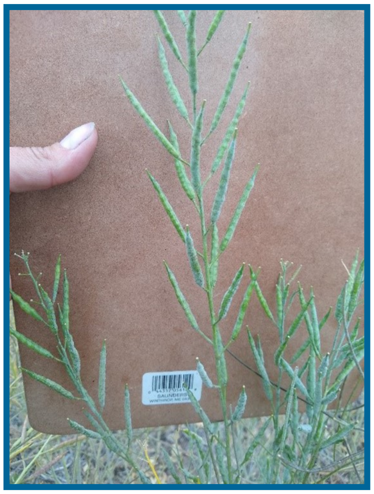

Figure 1. Example of pod count data being collected at Almira in 2019.

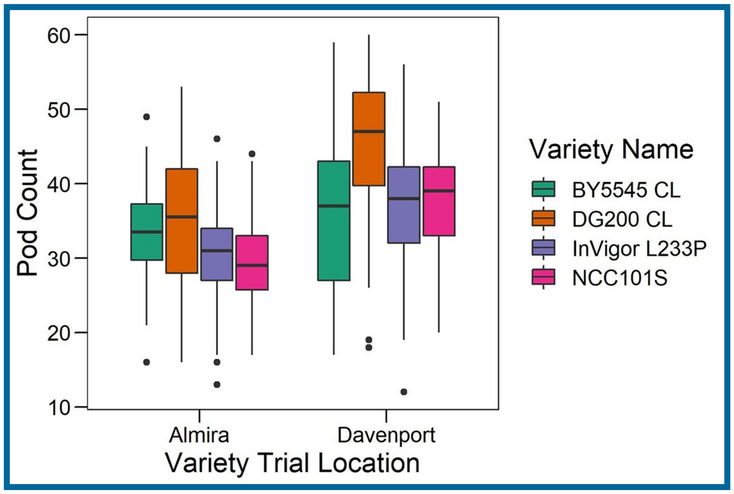

Figure 2. The boxplot shown here demonstrates the variation in pod counts at both Almira and Davenport. The boxplots presented here demonstrate that for each location there was a large amount of variation within and between varieties.

Almira and Davenport were 320 and 512 respectively allowing for a high spatial resolution of pod count variation across the study areas. The high spatial density at which the samples were taken demonstrates dramatic variation across relatively small intervals of space (Fig. 3 and 4). A further dissection of the data, by looking at variation within the yield map will serve to assist in better understanding whether the variation of yield within individual plots can be associated with the variation in pod counts.

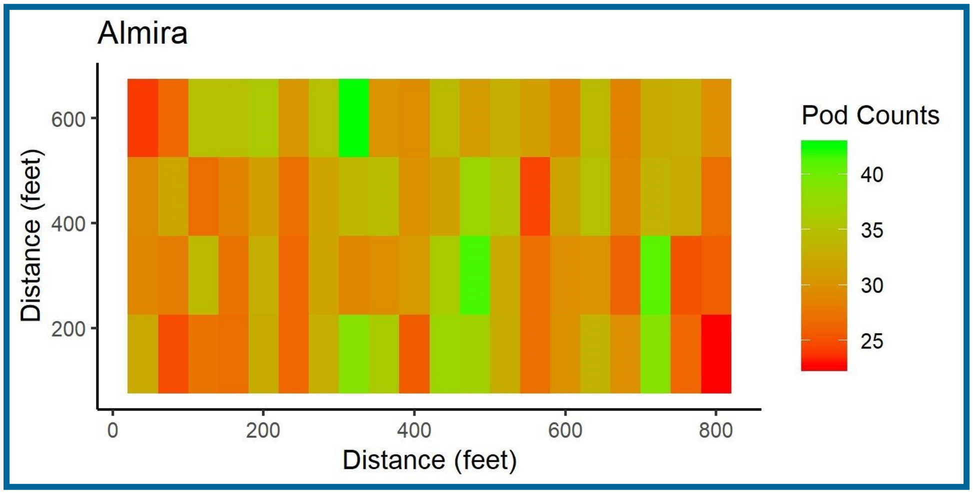

Figure 3. Variation in pod counts across the Almira strip trial. Pod counts at this location ranged from 13-53 pods. Each rectangle on the map represents the average of four pod counts made in the rectangle. In total, 320 plant counts were made at this location.

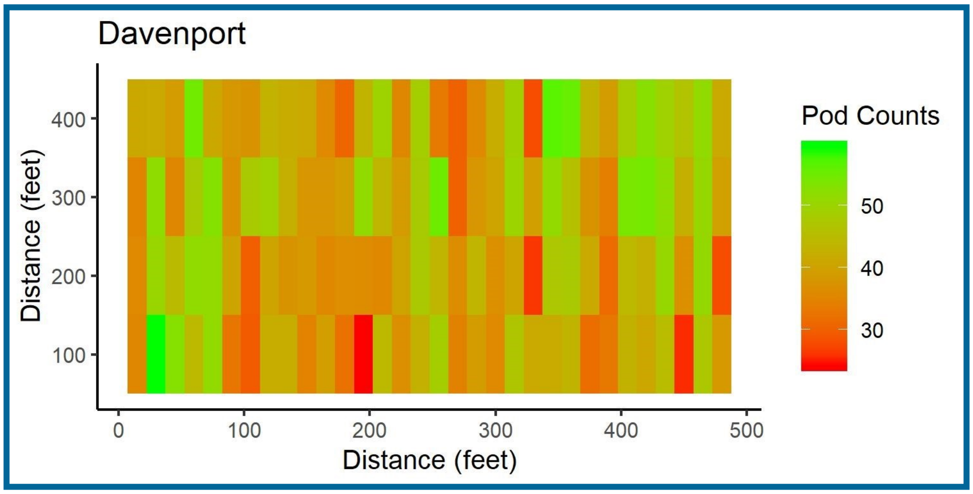

Figure 4. Variation in pod counts across the Davenport strip trial. Pod counts at this location ranged from 12-60 pods. Each rectangle on the map represents the average of four pod counts made in the rectangle. In total, 512 plant counts were made at this location.

Canola Variety Effects on Soil Health Mediated by Nutrients and the Microbiome

MAREN L. FRIESEN[1,2], TARAH SULLIVAN[2], TIMOTHY PAULITZ[1,3], HAIYING TAO[2], BRETT YOUNGINGER[1], AND RICHARD ALLEN WHITE III[1]
[1]DEPT. OF PLANT PATHOLOGY, WSU; [2]DEPT. OF CROP AND SOIL SCIENCES, WSU; [3]WHEAT HEALTH, GENETICS, AND QUALITY RESEARCH UNIT, USDA-ARS, WSU

The rhizosphere is a highly active region for both biological and chemical processes and is analogous to the human gut, where microbial communities play critical roles in transforming nutrients for the health of the host. Plants interact with a host of both soil-borne diseases and soil-borne beneficial micro-organisms and extensive work across plant systems has documented that plant genotype interacts with the environment to determine these interactions. Work by our team has found that crop genotype is related to differences in siderophore activity in wheat rhizosphere and that crop genotype is also related to differences in the ability for beneficial microbes to protect against soil-borne antagonists in the Medicago rhizosphere. In canola, one of the barriers to adoption is the variability in its effects on subsequent rotational crops--in some cases canola enhances the yield of following crops but in other cases it decreases yield. Previous work by our team has documented that wheat and canola share core rhizosphere microbiome members and that these communities shift through time and under varying canola-wheat rotations. However, it is not currently known how these effects vary with canola variety or if these effects are consistent across our region. Understanding the biological and soil nutrient basis of these effects in relation to canola variety across our region will be important for both immediate recommendations for farmers seeking to incorporate canola into rotations as well as longer term efforts to improve soil health through the use of oilseed crops.

We plan to sample the microbiome of ongoing variety trials–both the loosely bound rhizosphere, which has been more closely linked to microbiome function, as well as the tightly bound rhizosphere, which has been found to vary more dramatically across plant varieties due to genetic differences. We will extract DNA and use 16S and ITS to inform us what bacteria and fungi are present, and plan to additionally use high-throughput qPCR to assess the abundance of key nutrient cycling genes. We will also conduct analysis of soil nutrients in the bulk soil to better understand connections between canola varieties, the microbiome, and soil health.

Managing Nitrogen for Winter Canola

MARISSA PORTER, WILLIAM PAN, WILLIAM SCHILLINGER, ISAAC MADSEN, KAREN SOWERS, AND HAIYING TAO
DEPT. OF CROP AND SOIL SCIENCES, WSU

Currently, the yield-goal method is used to estimate nitrogen (N) rates for canola. In another words, N rate is determined based on unit N requirements (UNR), which is N requirement for a unit yield. A 12 site-year research study conducted across rainfall zones in WA found that approximately 7 to 17 lbs N per 100 lb seed yield is required for spring canola (UNR=7 to 17). In general, the higher the yield potential, the lower the UNR. When spring canola is grown in higher yield potential areas, it develops more vigorous root systems that allow greater access to soil nitrogen and water. Since winter canola yield potential vary substantially across rainfall zones, it is important that we provide the right UNR for farmers for winter canola.

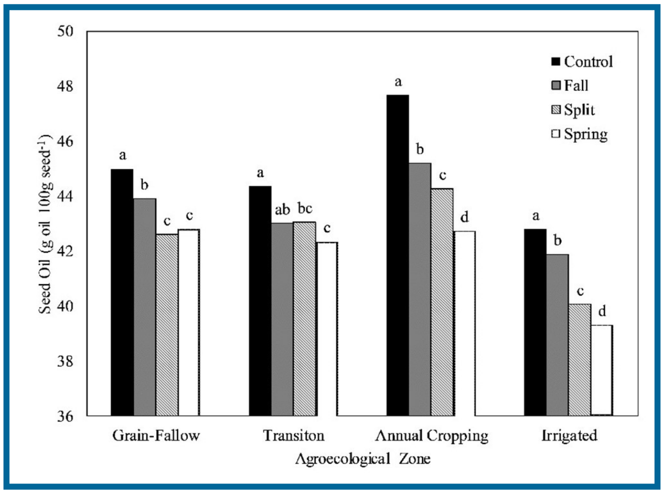

Figure 1. The relationship between average seed oil concentration and timing of N application for the different rainfall zones. Seed oil concentration marked by different letters above the bars are significantly different within each rainfall zone.

We conducted a N response study on 7 site-years across rainfall zones of WA and OR in 2016-2018. The treatments included N rates from 0 to 200 lbs/acre and N application timing including spring, fall, and split (50% in spring and 50% in fall). A uniform rate of ammonium sulfate was applied for all treatments. We found that approximately 5 to 7 lb N per 100 lb seed yield is sufficient for winter canola across all rainfall zones (UNR=5 to 7). Notably, however, when soil test N is higher than 100 ppm in the 6-foot depth, yield response to

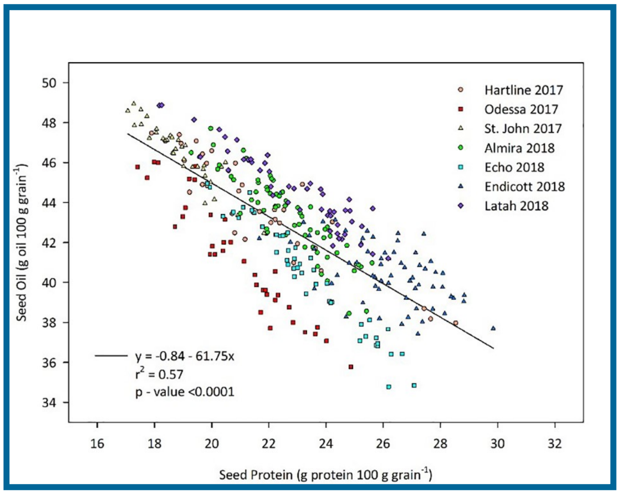

Figure 2. The inverse relationship between winter canola seed oil and protein concentration. Data points represent all treatment combinations from seven sites in the 2016–2017 and 2017–2018 crop years.

additional N fertilizer application is unlikely in winter canola, and this agrees with the study for spring canola. Therefore, farmers should determine N rate based on yield goal, UNR, and soil test.

Timing of N application affects N use efficiency, N availability to winter canola, and yield (Fig. 1). Spring application is a better practice than fall application in areas with high leaching potential, such as fields located in intermediate and high rainfall zones and sandy soils. In the high rainfall zone, if soil test N is higher than 100 ppm in fall, no fertilizer N application is needed; if soil test N is low, 30 lbs/acre N as starter is recommended and apply the remaining N in spring. Fall or splitting N applications between fall and spring in the low rainfall zone are good practices. Split application results in better yield in irrigated systems.

Canola seed quality is significantly affected by N management. Higher N availability leads to higher seed protein concentration. Typically, the higher the seed protein concentration, the lower the seed oil concentration (Fig. 2). Timing of N application also affects seed oil concentration, mainly as a result of the timing effect on N availability. For example, in the 7 site-year research, we found that winter canola seed oil concentration was lowest with spring N application in a field located in the high rainfall zone. For that same field, the next lowest oil concentration was the split applications between fall and spring, followed by fall application.

Understanding the Epidemiology of Blackleg Disease of Canola in Northern Idaho and Eastern Washington

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KAYLA YEAROUT[1], TIMOTHY PAULITZ[2], AND KURTIS SCHROEDER[1]
[1]DEPT. OF PLANT SCIENCES, UI; [2]USDA-ARS PULLMAN, WHEAT HEALTH, GENETICS AND QUALITY RESEARCH UNIT

The fungal pathogen *Leptosphaeria maculans* is the causal agent of blackleg disease of *Brassica napus,* otherwise known as canola. Due to the ability of *L. maculans* to infect every part of the plant during all developmental stages, blackleg is the most devastating disease of canola worldwide, with the potential to cause extreme crop damage and yield loss. In northern Idaho blackleg was first identified in 2011. Being a new disease in the region and the epidemiology of blackleg changing depending on climate, research has been conducted to understand the biology of *L. maculans* and its epidemiology specific to this region.

A major method of blackleg control is the use of resistant canola cultivars. This is a gene-for-gene mechanism in which a specific resistance gene in the plant confers resistance to *L. maculans* isolates that carry a corresponding avirulence gene. This gene-for-gene interaction can be highly effective, although this mechanism can break down over time with changes in the genetics of the pathogen much in the same way that we observe race shifts in stripe rust of wheat. To expand our understanding of the pathogen, a collection of 97 *L. maculans* isolates from eastern Washington were collected and screened in a plant host differential using multiple canola cultivars with known resistance genes. As of May 2020, 83 isolates have been screened. Gene frequencies (Fig. 1) show that 100% of the isolates contain AvrLm5-*6-7-LepR1-LepR2.* This data can be used by breeders to develop new canola varieties with enhanced resistance.

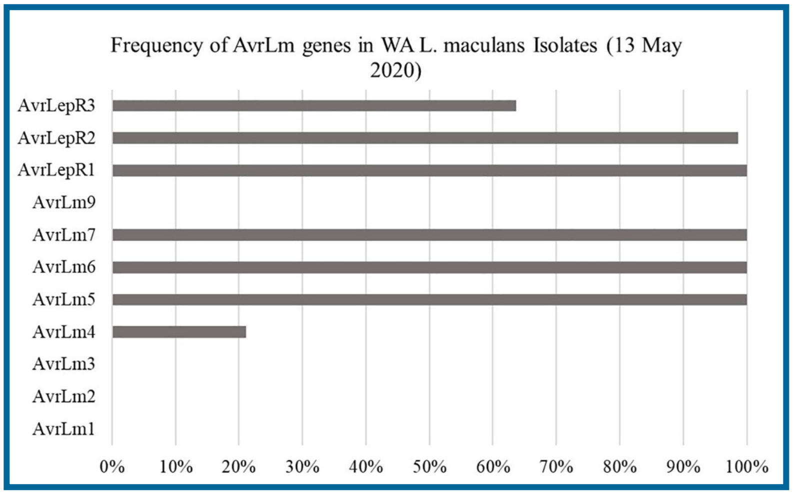

Figure 1. Frequency of *AvrLm* genes in the WA *L. maculans* isolates.

A second component of the research is to understand when spores are moving during the growing season. Burkard volumetric spore traps (Fig. 2) have been placed at two field trials where blackleg lesions were previously identified to determine when spores of *L. maculans* are being released and if the main source of infection is from wind-blown spores (ascospores) or rain-splashed spores (conidia). These traps pump air through an orifice and deposit any particles on a piece of tape. This tape is then sectioned into daily samples and are used for direct visualization on microscope slides or can be used in conjunction with PCR to look for DNA of a target organism. As of May 2020, ascospores have not been observed on slides, suggesting that the main source of infection is from conidia or infected seed. Weather station data will be paired with these spore counts to aid in identifying the environmental conditions and time of year when spores are released, in turn contributing to the development of grower guidelines for best management practices to use preventative fungicides.

To test the effectiveness of fungicide applications to limit blackleg, field trials were planted in Moscow, Genesee, and Grangeville (Fig. 3). These trials include winter canola cultivar Mercedes (resistant to blackleg) and Amanda (susceptible to blackleg) in conjunction with a combination of fungicide seed treatment and foliar applications. Foliar fungicide treatments include a fall only, spring only, a fall and spring, and no application. These trials are being monitored for blackleg incidence and severity as well as determining seed yield and oil content. This research will aid growers in making management decisions to minimize the impact of blackleg to canola.

Figure 2. Burkard Volumetric spore trap.

Figure 3. Fungicide field trial in Grangeville, ID.

Low Erucic Acid (LowE) Camelina Breeding Lines with Potential for Public Release

WILSON A. CRAINE[1], IAN C. BURKE[1], PHILIP D. BATES[2], AND SCOT H. HULBERT[1]
[1]DEPT. OF CROP AND SOIL SCIENCES, WSU; [2]INSTITUTE OF BIOLOGICAL CHEMISTRY, WSU

Camelina is a potential alternative crop for the sustainable intensification of dryland cropping systems due to minimal input requirements, strong adaptability to diverse environmental conditions, and its unique, “heart-healthy” fatty acid profile. Camelina is a rich source of both α-linolenic (18:3; 35-45%) and linoleic (18:2; 15-23%) acids, two essential fatty acids for human and animal health, and antioxidants called tocopherols (vitamin-E). Unfortunately, erucic acid content in camelina oil (2-5%) exceeds the 2% FDA threshold allowed for edible oil. Therefore, development of lines with less than 2% erucic acid content suitable for human consumption will greatly expand the marketability and profitability of camelina.

The WSU Camelina Breeding program has developed several elite breeding lines with low erucic content (lowE) that also exhibit good agronomic performance. During the 2019 field season, 12 advanced (lowE) breeding lines and 6 check varieties were tested in a replicated field trial in Pullman, WA. There were two seeding dates, May 10 and May 23, and at least four replicated plots (5ft x 9ft) of each genotype (16 for Calena and Suneson) per seeding date, arranged in a randomized complete block design (RCBD). Overall, the lines performed similarly in both seeding dates, so only means across seeding dates for each line is given.

Table 1 details the performance of four elite lowE lines and size check varieties, sorted from highest to lowest yield. There were two lines, #43 (0.57%) and #44 (0.46%) with significantly lower erucic acid content than any of the other lowE lines. Although #44 has the lowest erucic acid content of all, #43 had greater mean yield with significantly larger seeds (1.23 mg/seed) than #44 (1.05 mg/seed). Other promising lowE lines include #35, the highest yielding line (1339.3lbs/acre) with 1.91% erucic acid, and #38, the second highest yielding (1191.9 lbs/acre) and second highest oil content (43.22%) line with 1.56% erucic acid. Overall, #44 is inferior to the check varities in most of the agronomic categories, while #43 is competitive with the checks. Both #35 and #38 outperform the check varieties in both yield and oil content. With such low erucic acid content, we are confident #43 and #43, will maintain <2% erucic acid content across different environments/years. More testing is needed to confirm whether #35 and especially #38 will maintain <2% erucic acid content across different environments/years, but their higher yield potential may be worth that risk. Additionally, there is potential to mix lowE lines like #43 and #44 with higher erucic lines to dilute total erucic content below 2%. It is important to note that all lowE lines have significantly higher linoleic, α-linolenic, and total oil content than the checks.

Table 1. Grouped means for four elite LowE Breeding Lines and Check Lines. Lowercase letters denote significant differences (Tukey HSD) between means; "r" is the number of replicates per genotype.

r	Genotype	Yield (lbs/acre)	1SM (mg)	Oil (%)	Linoleic (%)	α-Linolenic (%)	Erucic (%)
8	LowE.44	876.8a	1.05b	41.57a	21.42ab	33.69a	0.46a
8	LowE.43	1021.1a	1.23ab	40.90ab	20.91abc	33.78a	0.57a
8	LowE.38	1191.9a	1.19ab	43.22a	22.16a	30.99b	1.56b
8	LowE.35	1339.2a	1.18ab	41.26a	18.35d	33.76a	1.91b
32	Suneson	1072.7a	1.24ab	36.04bc	21.30ab	31.37b	2.44c
8	BlaineCreek	999.7a	1.26a	35.10c	18.90cd	32.96ab	2.64cd
8	WA-HT1	1060.4a	1.24ab	35.9bc	19.06cd	33.57a	2.78cd
8	Midas	917.8a	1.32a	35.41c	19.59bcd	33.35ab	2.80cd
8	Cheyenne	1142.6a	1.33a	33.51c	18.37d	31.86ab	2.93d
32	Calena	1133.5a	1.28a	35.62c	19.54cd	33.35ab	3.00d

Biodiesel and renewable jet fuel are still good options for camelina oil, but development of lowE camelina lines suitable for human consumption will greatly expand the marketability and profitability of this crop. The WSU Camelina Breeding Program plans to publicly release lowE line(s) summer 2020.

*Note: The WSU Camelina Breeding Program released WA-HT1, a group II soil herbicide resistant variety, in 2018. All of these lowE lines have that herbicide tolerant trait and exhibit resistance to soil residual levels of group II herbicides.

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Spring Canola and Chickpea Value in a Cereal Grain Rotation

Aaron D. Esser[1], Jack Brown[2], and James B. Davis[2]
[1]WSU Extension; [2]Dept. of Plant Science, UI

Canola (*Brassica napus* L.) has been a rotation option with wheat (*Triticum aestivum*) for farmers in the dryland cropping region of the Pacific Norwest for over 25 years, yet adoption has been limited because of market access, profitability and overall unfamiliarity with the crop. In 2014 a large-scale multi-year rotation study was initiated comparing spring wheat, canola and chickpea (*Cicer arietinum* L.) (1st year) in rotation with winter wheat (WW) (2nd year) and spring wheat (3rd year). The study was located at the WSU Wilke Research and Extension Farm which receives an average of 14 inches of precipitation. The experimental design was a randomized complete block with four replications and plot size 25x200 feet. Each crop rotation is examined over two cycles (i.e. 6 years) and was repeated in 2015 and 2016. Data presented here focuses on the three treatment crops and includes seed yield, production costs, and economic returns. Over the 6 years, spring wheat had the highest yield, averaging 2,134 lbs./ac (35.6 bu/ac), and there was no significant difference in yield between canola and chickpea 1,014 and 963 lbs./ac, respectively. Gross economic returns were calculated using local F.O.B. prices on September 15 each year, and canola and chickpea yearly contract prices. Chickpea and wheat had the greatest gross economic return at $214 and $199/ac, respectively, compared to canola at $166/ac. Production costs considered included only seed, fertilizer, and herbicide costs. Over the six years wheat had the lowest production costs at $100/ac, and canola and chickpea both averaged $116/ac. Overall wheat and chickpea produce the greatest economic return to growers over costs at $99 and $97/ac, respectively, and canola produced $48/ac over costs. In conclusion market price is a major component of potential profitability of wheat, chickpea and canola.

Treatment	Yield (lbs./ac)	Market Price ($/lb)	Gross Economic Return ($/ac)	Cost ($/ac)	Economic Return over Costs ($/ac)
Wheat	2134 a	0.093	199 a	100	99 a
Canola	1014 b	0.162	165 b	116	48 b
Chickpea	963 b	0.222	214 a	116	97 a
LSD (P<0.05)	134		21		21

Means within columns with different lowercase letters are significant (P<0.05).

Soil Water Dynamics with Camelina in a Three-Year Rotation in Washington's Winter Wheat-Fallow Region

Stewart Wuest[1] and Bill Schillinger[2]
[1]USDA-ARS; [2]Dept. of Crop and Soil Sciences, WSU Lind

Camelina of the *Brassicaceae* family is a short-season oilseed with tolerance to water stress and frost. Camelina has been promoted as a potential alternative crop for the low-precipitation (<12 inch annual) Mediterranean-like climate region of inland Pacific Northwest where a monoculture 2-yr winter wheat-summer fallow (WW—SF) rotation is practiced by the vast majority of farmers. An 8-yr field experiment was conducted at Lind, WA to compare a 3-yr WW—camelina—SF rotation to the typical 2-yr WW—SF rotation. We conducted a detailed analysis of soil water dynamics of these two crop rotations throughout the experiment. Growing camelina reduced soil water content at the beginning of the fallow period, and this reduction resulted in an average of 0.83 inches less water at the time of WW planting and a 2.5 bushel/acre reduction in grain yield compared to WW—SF. Compared to WW—SF, we found that: (i) the deep-rooted broadleaf weed Russian thistle present in camelina most years was a likely reason for significantly greater in-crop soil water use, and (ii) the limited residue produced by camelina was likely responsible for greater evaporative loss during the spring-through-late-summer segment of fallow. These are the first findings from the Pacific Northwest drylands of greater water use by a cool-season spring crop versus WW as well as greater evaporative loss during the dry summer months due to lack of residue during fallow. In this experiment, extending the crop rotation to include camelina was costly in terms of water use, surface soil residue cover, soil water storage during fallow, and WW grain yield. Read the full article here: https://acsess.onlinelibrary.wiley.com/doi/full/10.2136/sssaj2019.05.0157.

Developing Diagnosis and Recommendation Integrated System for Micronutrients in Spring Canola

Isaac J. Madsen, Haiying Tao, and William L. Pan
Dept. of Crop and Soil Sciences, WSU

Macronutrient and micronutrient concentrations in tissue tests vary between crop species. Additionally, tissue concentrations may also vary between varieties in a single crop species. In crops such as canola (*Brassica napus*) critical values might be used from a closely related crop species such as rapeseed (*Brassica rapa*), without validating the critical values for the crop of interest. In addition to the variations between and within species there may also be wide spatial variation within fields. In order to assess some of these variations and work towards establishing critical values in the inland Pacific Northwest we collected tissue samples from winter and spring canola trials in Washington. We sampled farm scale variety trials in order to assess the variation between crop cultivars and the variation across a field within individual cultivars. The strip were 40 feet wide by 600 feet long and contained five varieties replicated four times coming to total of 11 acres. The strip trial was established near Almira, WA following winter peas. The tissue samples were taken at the 4-6 leaf stage prior to bolting. The macronutrient and micronutrient concentrations varied greatly based on both cultivar and location within the field. Of the five varieties included in this trial four varieties were napus (NCC101S, BY5545, InVigor L233P, and DG200) while one was rapa (Xceed DG X122 CL). The rapa cultivar contained significantly higher concentrations K, Fe, Zn, and B than any of the napus type cultivars (Table 1 and Table 2). This of interest to research and production as Zn and B are micronutrients of special concern in the inland Pacific Northwest. Additionally, all the macronutrients showed significant variation between napus type cultivars (Table 1). In addition to the variation between different varieties, the spatial variability of nutrient concentrations within the field was assessed. The concentrations of both macronutrients and micronutrients varied widely across strip trial. For example, N ranged from 3.35%-5.24% (Fig. 1). The Future work will focus on linking plant tissue concentration to yield.

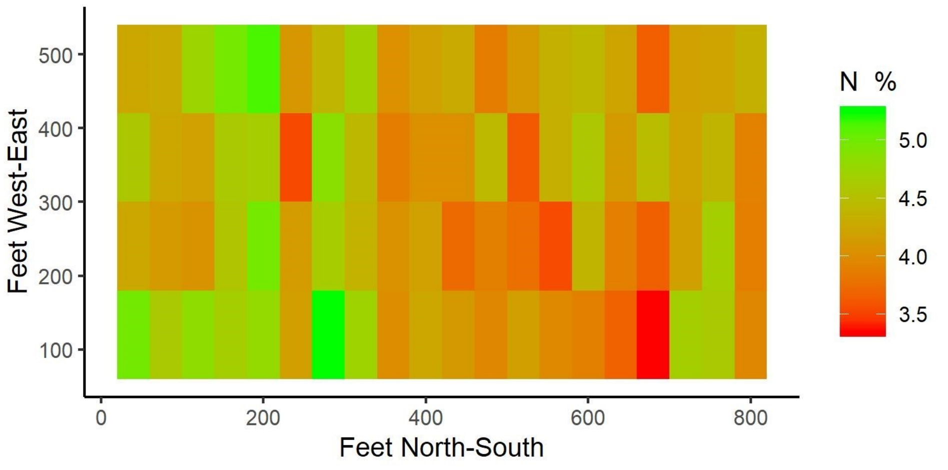


Figure 1: Nitrogen tissue concentrations vary from 3.35-5.42% across and 11 acre strip trial. Similar variations were found in other macronutrients and micronutrients. The variability in plant nutrient concentration across the field demonstrates the importance of adequate sampling density and distribution when taking nutrient samples.

Table 1.

	Macronutrients (%)											
Variety Name	N		P		K		S		Ca		Mg	
Xceed DG X122 CL	4.191	b	0.522	ab	5.411	a	0.588	bc	1.089	c	0.314	abc
NCC101S	4.006	b	0.510	b	4.317	c	0.538	c	1.166	c	0.302	bc
BY5545 CL	4.117	b	0.505	b	3.961	d	0.626	ab	1.266	b	0.301	c
InVigor L233P	4.570	a	0.547	a	5.068	b	0.577	bc	1.270	b	0.321	ab
DG200 CL	4.449	a	0.534	ab	4.442	c	0.654	a	1.384	a	0.322	a
CV	7.921		8.233		7.730		12.335		9.359		8.748	
LSD	0.238		0.030		0.253		0.052		0.081		0.019	

Table 2.

	Micronutrients (ppm)													
Variety Name	Fe		Cu		Zn		Mn		Cl		B		Mo	
Xceed DG X122 CL	317.75	a	4.60	a	35.89	a	69.06	ab	0.36	c	29.13	a	0.72	a
NCC101S	135.94	b	4.21	a	24.57	d	64.76	b	0.53	a	23.06	b	0.69	a
BY5545 CL	137.44	b	4.39	a	27.30	bc	63.39	b	0.46	b	22.25	b	0.57	b
InVigor L233P	172.38	b	4.53	a	27.92	b	64.76	b	0.46	b	22.44	b	0.75	a
DG200 CL	135.25	b	4.16	a	25.60	cd	72.83	a	0.49	ab	23.63	b	0.68	a
CV	30.11		16.17		8.64		13.27		15.58		12.96		18.46	
LSD	38.12		0.50		1.72		6.26		0.05		2.20		0.09	

Nitrogen Source and Rate to Minimize Damage Caused by Free Ammonia

ISAAC MADSEN AND WILLIAM PAN
DEPT. OF CROP AND SOIL SCIENCES, WSU

When planning N fertilizer application, the source of the fertilizer should be considered in order to optimize nutrient availability as well as to avoid damaging seedling root systems. Canola root systems have been shown to be sensitive to urea banded below the seeds. The two primary considerations when choosing a safe source of N fertilizer are the salt toxicity and ammonia/ ammonium toxicity. The conversion of ammonium to free ammonia is primarily controlled by the initial pH of the fertilizer reaction. A high pH will lead to more free ammonia than ammonium. Free ammonia has been shown to be extremely toxic to plant cells. Therefore fertilizers with a high pH would be expected to release more free ammonia and consequently have a higher level of toxicity. Urea, Anhydrous Ammonia, and Aqua Ammonia all have pH greater than 8 in solution. Fertilizers with a pH lower than 8 are Ammonium Sulfate, Mono-Ammonium Phosphate, and Di-Ammonium Phosphate. In this study we compared the application of ammonium sulfate (AS) (pH = 5-6, partial salt index = 3.52), urea (pH = 8.5-9.5, partial salt index = 1.61), and urea ammonium nitrate (UAN) (pH = 7, partial salt index = 2.22). In order to establish safe planting guidelines a root assay was conducted in a Palouse Silt Loam soil with N fertilizer sources banded 2” below the seed row at increasing rates. The gradients of the rates were used to model tap root survival and estimate the LD50s for tap root survival. The LD50 is the rate at which would expect 50% of the tap roots to die. The unconventional unit of mg/cm was used to make the applications and dose response because the actual amount of N which the root is exposed to depends heavily on the row spacing and the application rate (lbs N/ A). In table 1 you can see a conversion between the LD50 (mg/cm) and field rates (lbs N/A) at different row spacings for all three sources. From this table you can see that UAN is a much safer source of N to apply than UAN and that closer row spacing will also decrease the potential for root death.

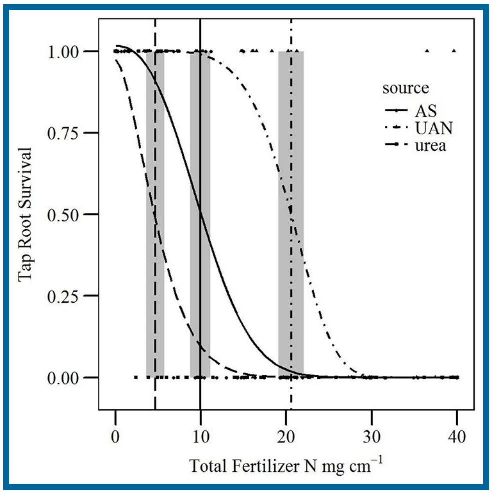


Figure 1. Modeled dose response and estimated LD50s for Ammonium Sulfate (AS), Urea Ammonium Nitrate (UAN), and Urea. LD50s can be converted to lbs N/A for each source by using Table 1.

Take away points: It was determined that canola roots are more sensitive to urea than ammonium sulfate or UAN. This is likely because urea would produce higher levels of free ammonia following dissolution.

Table 1. LD50s of canola tap root survival exposed urea, AS, and UAN.

Source	LD50 (mg N/cm)	Row Spacing (in) 6	12	18
		Rate (lbs N/A)		
urea	4.7	27	14	9
AS	9.7	57	28	19
UAN	20.6	120	60	40

Use of Transgenic and Agronomic Approaches to Improve Stand Establishment and Survival in Winter Canola

SHAHBAZ AHMED AND MICHAEL M. NEFF
DEPT. OF CROP AND SOIL SCIENCES, WSU

Expanding oilseed cultivation in the Pacific Northwest (PNW) is important not only for edible oil production for human consumption but also as a rotation crop with winter wheat. Both winter and spring canola are being grown in the PNW, but winter canola has more yield potential compared to spring canola in this region. Winter survival of canola depends on many factors including the planting date, seeding depth, seeding rate, stand establishment, plant stature, and cultivar genetics. In a recently funded project, our lab is using a combination of transgenic and agronomic approaches to study and improve the winter survivability of winter canola in the inland PNW. In our transgenic approach to improve stand establishment, we are using an allele variant, *Atsob3-6,* of a DNA-binding protein SOB3/AHL27, which regulates seed size and seedling development in *Arabidopsis* and *Camelina sativa,* both belonging to the same family as canola. In *Camelina sativa,* our lab developed transgenic plants resulted in bigger seeds (Fig. 1) and improved seedling emergence at greater planting depths (Fig. 2) (Koirala and Neff, 2019). We are using the same allele to make transgenic canola through tissue culture to develop plants with increased seed size and improved seedling emergence. Improved stand establishment via early planting results in an increase in plant size, however, this can favor winter kill. In contrast, late planting results in seedlings that are too small to withstand winter kill. Thus, optimum plant size is important in winter canola varieties for survival through harsh winter conditions. In our agronomic approach, we are using the plant growth regulator (PGR) gibberellin (GA) to manipulate plant development. In our study, commercial varieties of canola are being treated with different concentrations of GA-related PGRs. GA-biosynthesis inhibitors are being tested out in a dose-response manner on early-planted juvenile canola plants to delay development to maintain the optimum plant size before the winter onset. In contrast, experiments are also being performed with growth-promoting GAs to increase plant size for late-planted juvenile canola plants. Our lab will also be carrying out a winter tolerance screen on a large collection of canola germplasm in the inland PNW region. In collaboration with the winter wheat program, we will be using an image-based phenotyping approach to screen germplasm based on winter survivability. A multi-year trial of this experiment would allow us to understand the genetics of winter tolerance, as well as identify lines with better winter survival to incorporate into future winter canola breeding programs. Together, these transgenic and agronomic approaches will allow us to develop new germplasm and agronomic practices to increase stand establishment and winter-kill tolerance, with the ultimate goal of increasing canola acreage in the PNW.

Koirala, P.S. and Neff M.M. (*in review for Transgenic Research*) Improving seed size and seedling emergence in transgenic *Camelina sativa* by overexpressing the Atsob3-6 gene variant.

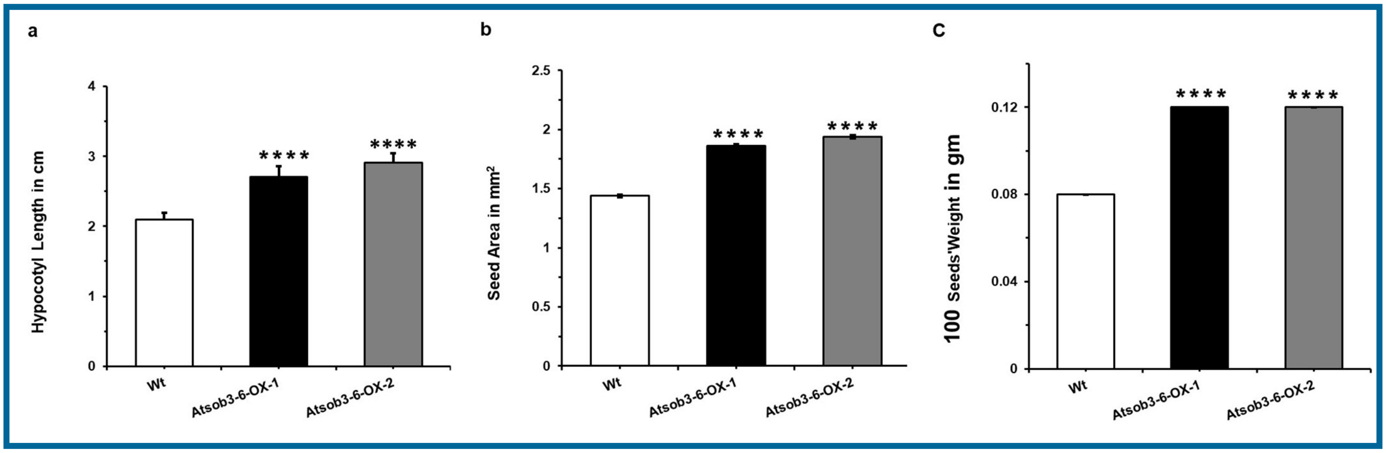


Figure 1. **<u>The *Atsob3-6* allele regulates hypocotyl length, seed size and seed weight when overexpressed in *Camelina.*</u> Two independent *Atsob3-6-OX* transgenic *Camelina* lines displayed increased hypocotyl length (a) seed size (b) and seed weight (c) when compared to the wild type (Wt). *n* = 60 for hypocotyl length. *n* = 100 for seed area. *n* = 300 for seed weight, **** p < 0.0001**

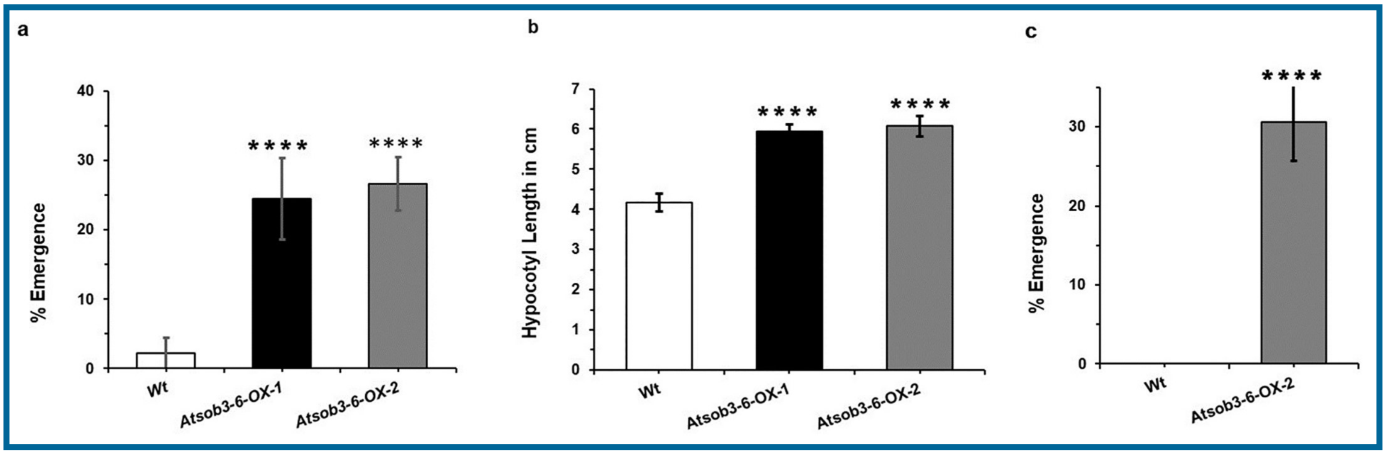


Figure 2. **<u>*Atsob3-6-OX* confers better seedlings emergence in *Camelina.*</u> Seeds of *Atsob3-6-OX* line and the wild type were germinated beneath 6 cm of lightly compacted potting mix at 25°C for seven days before measuring percent emergence (a), and total hypocotyl length within and above the soil (b). Seedling emergence of *Atsob3-6-OX-2* and wild-type seedlings was also measured seven days after planting beneath 6 cm of dry Palouse silt loam (c). *n* = 36, *****p*< 0.0001.**

Mixed Canolage – Companion Cropping of Dual-Purpose Winter Canola

ISAAC J. MADSEN[1] AND STEVE VANVLEET[2]
[1]DEPT. OF CROP AND SOIL SCIENCES, WSU; [2]DEPT. OF AGRICULTURE AND NATURAL RESOURCES

Figure 1. Mixed canolage (oat-canola intercrop grown for forage and canola seed) prior to grazing.

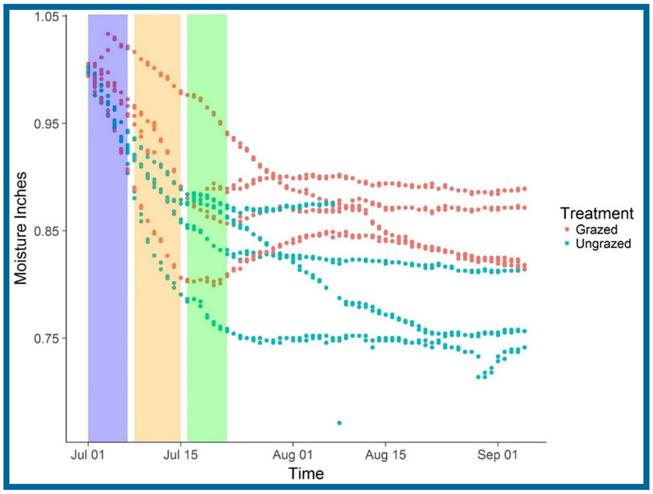


Figure 2. The change in relative moisture following the initiation of grazing in the first week of July. In most cases, the un-grazed plots used more than the grazed plots over the recorded time frame.

Dual purpose canola is the practice of seeding winter canola during the summer and harvesting the biomass as a forage in the season prior to seed harvest. The harvest may occur either by swathing or cattle grazing. Dual purpose canola has sometimes been referred to as canolage. As canolage is a more concise term we will use it here. In some cases, canolage may be mixed with other plant species in order to control plant maturity and add biodiversity to the system. During the summer of 2019 two mixed canolage studies were established. The companion crop used in both cases was spring forage oats (Fig. 1). The two locations were Dusty, WA and Creston, WA. The Dusty location was established the last week in May and the Creston location was established the first week in July. During the summer and fall of 2019 a variety of data were collected at the Dusty location. The data collected was forage tests, plant counts, and soil moisture. The forage tests were used to compare the monoculture canolage with the mixed canolage (Table 1). The mixed canolage had a higher dry matter, acid detergent fiber, and neutral detergent fiber value. The monoculture canolage had higher crude protein and relative feed values. The higher dry matter, ADF, and NDF of the mixed canolage is preferred to the monoculture canolage as the fiber is necessary for ruminant digestion to function well. In addition to the forage test moisture monitoring stations were established at four grazed and four un-grazed locations. At each location, a sensor was installed at 1, 2, 3, and 4-foot depths. The different depths were added to calculate the total moisture in the profile. In order to assess the impact of grazing on the moisture in the profile the relative moisture was calculated based on the moisture at the start of grazing and the changes in the moisture over the period of grazing were logged (Fig. 2). Figure 2 shows that the grazed plots (pink) used less relative moisture than the un-grazed (blue) plots. This indicates that grazing mixed canolage may reduce the overall water usage of the system when compared with the un-grazed system. Late in the fall most of the Dusty plots had droughted out, and only a subset of the field will be taken to harvest. In the spring of 2020, all but a small section of the canola was terminated. The drought out at the Dusty location is likely due to the early planting date. The Creston location had good winter survival and the full area will be harvested in the July of 2020.

Table 1. Forage values for monoculture canola compared to oat-canola mix.

	Canola	Oat & Canola
Dry Matter	11.6	19
Crude Protein	21.3	14.2
Acid Detergent Fiber (ADF)	16.9	20.2
Neutral Detergent Fiber (NDF)	17.3	29.5
Relative Feed Value (Estimated)	407	231

Impact of Flea Beetle Damage, Insecticide Application, and Delayed Seeding Dates in Spring Brassica Crops

Jim B. Davis, Ashley Job, Megan Wingerson, and Jack Brown
Dept. of Plant Sciences, UI

Flea beetle is recognized as a major pest of canola (*Brassica napus* and *B. rapa*) and mustard (*B. juncea* and *Sinapis alba*). Yield losses from flea beetle feeding on *B. napus* canola have been found to be between 7% and 35% in north-central Idaho. Control strategies for flea beetle are based on the use of insecticidal seed treatments such as Helix Vibrance or Prosper EverGol at the time of planting combined with post-emergence, foliar sprays when damage reaches 20 to 25% defoliation.

Four spring canola/rapeseed cultivars (*B. napus*) with differing maturities and an Indian mustard (*B. juncea*) were used in this two-year study at Moscow, Idaho. The seed of all cultivars was treated with Helix Vibrance at the label rate. Each cultivar was seeded at three different seeding dates at two-week intervals: April 25/May 1, May 8/May14, and May 23/May 28, 2018/2019, respectively. At each seeding date, the plots were arranged in blocks that would be sprayed with a foliar insecticide (Warrior II plus and R56 adjuvant) and blocks that would not be sprayed.

Flea beetle pressure was relatively low during the study, with an average damage rating of 7.6 (on a scale of 1 to 9, with 9 being no damage). Data for each of the cultivars tested are shown in Table 1. Seed yield was significantly and dramatically affected by seeding date (Table 2). The seed yields from the three seeding dates, early to late, were 2,282, 1,870, and 1,062 lbs. per acre; the 4-week delay in seeding resulted in a 53% yield loss. The effect of the foliar insecticide varied across planting dates and years. Averaged across the trial, foliar insecticide application improved flea beetle damage scores from 7.5 to 7.7, a small but statistically significant improvement, while seed yield improved from 1,661 lbs. per acre to 1,818 lbs. per acre, a difference of 157 lbs. The greatest difference in yield due to insecticide spray treatment was seen in the early planting in 2018, when spraying a foliar insecticide increased yield by 260 lbs. per acre.

Table 1. Mean flea beetle damage score (scale of 1 to 9 with 9 being no damage), days from seeding to 50% flowering, and seed yield of five Brassica cultivars grown near Moscow, Idaho in 2018 and 2019.

Cultivars	Flea Beetle Damage	Days to Flower	Seed Yield (lbs./acre)
Pacific Gold Mustard	7.0^{a}	41^{a}	1,635^{a}
Industrious Rapeseed	7.6^{b}	43^{b}	1,613^{a}
HyCLASS 930 RR	7.7^{b}	45^{c}	1,926^{b}
Star 402 RR	7.7^{b}	47^{d}	1,866^{b}
DynaGro 200 CL	8.1^{c}	50^{e}	1,658^{a}
Mean	7.6	45	1740
LSD (p=0.05)	0.2	0.3	122

Means within columns with different superscript letters are significantly different (P<0.05)

An examination of flowering data suggests reasons for the yield decrease seen with later seeding dates (Table 3). With each two-week delay in seeding, the time of flowering was delayed 10 to 12 days. This pushed flowering and seed filling later in the summer to a time with higher temperatures and lower relative humidity, which would increase the environmental stress on the crop. The time from seeding to flowering also decreased as seeding was delayed. This likely reduced the amount of vegetative growth of the crop prior to flowering, which suggests that in addition to the seed fill period occurring in a more stressful environment, the plants were smaller and likely produced fewer resources for seed filling.

Table 2. Mean flea beetle damage score (scale of 1 to 9 with 9 being no damage) and seed yield of five Brassica cultivars with three seeding dates when grown near Moscow, Idaho in 2018 and 2019.

Seeding Dates	Flea Beetle Damage	Seed Yield (lbs./acre)
April 25/May 1	7.4^{a}	2,287^{a}
May 8/May14	7.4^{a}	1,870^{b}
May 23/May 28	8.1^{b}	1,062^{c}
LSD (p=0.05)	0.2	284

Means within columns with different superscript letters are significantly different (P<0.05)

This study showed that delaying planting until late May resulted in a slight decrease in flea beetle damage, perhaps due to a cessation of feeding as the adult flea beetles completed their life cycle and died, but any positive effect was far outweighed by yield losses associated with delayed planting. The study also showed that even with low flea beetle pressure, a foliar application of insecticide can be justified and will increase seed yields of spring canola. At a canola price of 17 cents per pound, the seed yield increase of 157 lbs. per acre observed in the trial has a value of $27 per acre. This should be enough to cover the cost of insecticide and application. Under higher flea beetle pressure, the economic return is likely to be greater.

Table 3. Mean flower date and days from seeding to 50% flowering of five Brassica cultivars with three seeding dates when grown near Moscow, Idaho in 2018 and 2019.

Seeding Dates	Flower Date	Days to Flower
April 25/May 1	June 15 [a]	49 [a]
May 8/May14	June 25 [b]	45 [b]
May 23/May 28	July 7 [c]	42 [c]
LSD (p=0.05)	0.3	0.3

Means within columns with different superscript letters are significantly different (*P*<0.05)

Canola in Cereal-Based Rotations: Agronomy and Soil Microbiology Update from Ritzville

BILL SCHILLINGER[1], JOHN JACOBSEN[1], RON JIRAVA[2], JEREMY HANSEN[3], TIM PAULITZ[3], STEVE SCHOFSTOLL[1], AND DAVE HUGGINS[3]
[1]DEPT. OF CROP AND SOIL SCIENCES, WSU; [2]FARMER COLLABORATOR, RITZVILLE; [3]USDA-ARS

Two long-term canola cropping systems experiments were initiated in 2014 and 2016, respectively, on the Ron Jirava farm near Ritzville. In Study 1, canola is grown in a 4-year rotation of C-F-WW-F and is compared to WP-F-WW-F as well as a 2-year WW-F check. In Study 2, canola grown in a 3-year C-SW-F rotation is compared to 3-year rotations of WW-SW-F and WT-SW-F (all acronyms used are defined at the end of this report).

Some research highlights from Study 2 are briefly outlined here. Note that SW follows C, WW, and WT and that a 13-month fallow period occurs after SW in all three rotations. Overwinter precipitation storage in the soil has been significantly lower after canola in some, but not all, years compared to after WT or WW (Fig. 1). We are surprised by these data because in a previous 6-year study near Davenport there were never any differences in overwinter precipitation storage in the soil after canola versus wheat. To date, SW grain yields averaged over years at our Ritzville site have been significantly lower after canola versus WT and WW (Fig. 1).

Is the difference in overwinter precipitation storage in the soil the reason for the differences in SW grain yield among treatments? The answer is "not entirely". Figure 2 shows that 33% of the difference in SW grain yield among treatments is due to the amount of water in the 6-foot profile in late March. The remaining 67% of the grain yield difference among treatments is due to some other factors. The PhD dissertation research conducted by Jeremy Hansen in the above-mentioned Davenport study showed that soil microbial populations, including mycorrhizal fungi, were reduced with canola compared to wheat (click this link for the full report of this study https://www.frontiersin.org/articles/10.3389/fmicb.2019.01488/full). Is this same phenomenon also taking place in our Ritzville study?

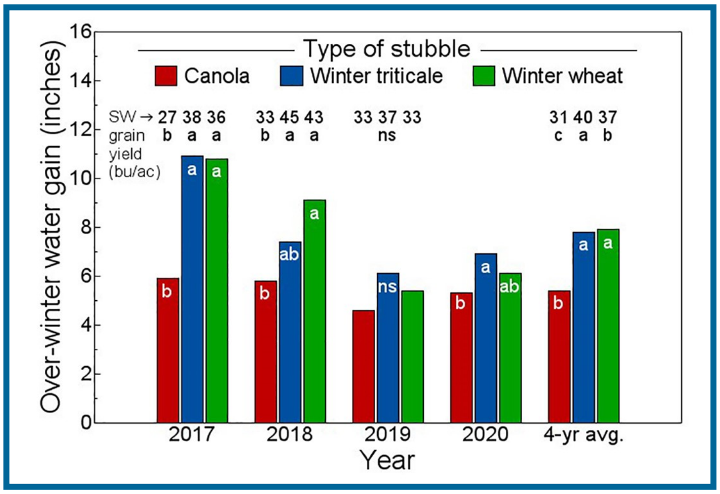


Figure 1. Overwinter gain in soil water in the 6-foot soil profile as affected by having canola (either spring or winter canola), winter triticale, and winter wheat as the previous crop. Soil water content at time of harvest of these crops was essentially identical every year. Stubble of the three crops was left standing and undisturbed after harvest. The numbers above the individual bars show spring wheat (SW) grain yield that was sown in late March into the stubble of the three previous crops. Letters within years (and averaged over the four years) followed by a different letter are significantly different at the 5% probability level. Ns = not significantly different.

Dr. Hansen is currently leading a study to determine if injecting mycorrhizal inoculum beneath newly emerged SW seedlings at our Ritzville site will enhance mycorrhizae populations and, if so, see how this affects SW grain yield. Concurrently, Dr. Tim Paulitz is conducting DNA sequencing of SW roots and soil adhering to the roots (i.e., rhizosphere soil) to measure the presence of numerous taxa of fungi and bacteria at the Ritzville site. We are excited about this research!

Finally, we need to state that there is no evidence that wheat yield is negatively affected when there is a year-long fallow period after a canola crop prior to planting wheat. On the contrary, there are numerous reports by scientists and farmers from around the world that show wheat yield is often enhanced when the previous crop is canola. Our collective research in the Pacific Northwest indicates that soil microbial biomass decline with canola is temporary and that soil microbial populations return to their previous levels in about one year.

Acronyms used: C, canola (either winter or spring canola); F, 13-month-long fallow; SW, spring wheat; WP, winter pea; WT, winter triticale; WW, winter wheat.

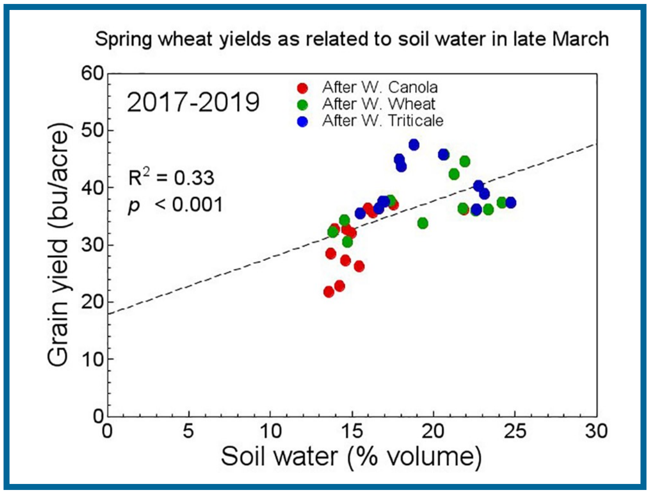


Figure 2. Relationship between soil water content in late March at time of sowing of spring wheat and the grain yield of spring wheat. The correlation coefficient (R^2) of 0.33 means that 33% of the difference in spring wheat grain yield following canola, winter triticale, and winter wheat is due to the amount of soil water in 6-foot soil profile in late March. The remaining 67% of spring wheat yield differences following canola, winter triticale, and winter wheat is due to other factors.

A Study to Support Phosphorus Fertility Recommendations for Winter and Spring Canola

Haiying Tao[1], Aaron Esser[2], Stephen Van Vleet[2], Isaac J. Madsen[1], and William L. Pan[1]
[1]Dept. of Crop and Soil Sciences, WSU; [2]WSU Extension

Phosphorus is an essential nutrient for crops. It is a structural element in many molecules such as ADP and ATP, nucleotides, nucleic acids, and co-enzymes. Sufficient amount of phosphorus supply during canola growing season ensures functionality of these molecules, strengthens seed formation, and prevents lodging as a result of better development of stem tissues. However, there are limited studies on phosphorus fertility strategies for canola (*Brassica napus*). In order to support phosphorus fertilizer recommendations for the Northwest, we initiated a small plot research on Washington State University Wilke Research and Extension Farm in the fall of 2019. We will use the small plot experiment to study yield and quality responses of winter canola to phosphorus application rate and application method. We established a field-scale research in Almira, WA to study spatial variability of such responses. In spring 2020, we were able to conduct one small plot research on Wilke Research and Extension Farm for a similar study for spring canola. In additional to phosphorus, the treatment included zinc which allows us to study the interaction effect of phosphorus and zinc on spring canola's yield and quality. We will repeat the study and conduct more research trials in 2021 and 2022. The results will be used to (1) determine agronomic and economic optimum rate for P for winter and spring canola yield and quality; (2) determine agronomic critical level for soil test phosphorus, above which no phosphorus should be applied; (3) determine the best placement strategy for P uptake, yield, and quality of winter and spring canola; (4) evaluate how soil and climate conditions affect crop yield response to P

Winter canola trial to study phosphorus fertility strategy (photo was taken on May 13, 2020).

fertilization, and within- and across-fields spatial variability in yield response on P. Farmers who would like to participate this research, please contact Dr. Haiying Tao at haiying.tao@wsu.edu. The more farmers participate in the research, the better recommendations will be developed for variety, soil, and weather.

Companion Crops as a Method for Improving Winter Canola Stand Establishment and Winter Survival

Isaac J. Madsen[1] and Aaron Esser[2]
[1]Dept. of Crop and Soil Sciences, WSU; [2]WSU Extension

Companion cropping is the practice of planting crops in proximity to one another with the objective of the plant species benefiting each other. Companion crops may be may exist of a single cash crop and one or more ‘companion’ crops. In general, the companion crop is grown with a specific benefit to the cash crop in mind. Modern mechanized agriculture has not used companion cropping to a large extent. However, certain companion cropping system have the potential to benefit mechanized agriculture. One system that is gaining interest is using spring oats as a nurse crop for winter canola in order to improve stand establishment and winter survival. In the fall of 2019 near Davenport, WA a trial was established comparing winter canola grown with a companion crop of oats to winter canola planted in a conventional monoculture. Fall (9/19/19) and spring (4/2/20) plant counts were taken to assess the effect of the companion oat crop on winter canola stand establishment and winter survival. The fall plant counts revealed no significant difference in the number of canola plants which successfully established. However, the companion cropping system showed a more uniform distribution (Fig. 1). The monoculture winter canola did show a significantly higher percentage of winter survival than the companion cropped winter canola (Fig. 2). The average winter survival in the monoculture canola was 51% while the average winter canola in the companion cropped canola was 34%. While the monoculture canola appeared to have a clear advantage over the companion cropped treatment in this system, we do not consider this brief study to have conclusively answered the question of whether or not companion cropping may have a role in the future of canola production. Anecdotal evidence has shown this practice to be effective in other regions, and we plan to pursue the roll of companion cropping in canola further. Future research will examine the effects planting date, and the density of the companion crop on stand establishment and winter survival.

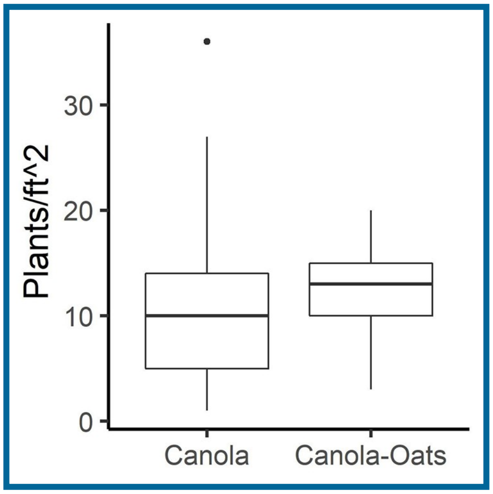


Figure 1. Box plot showing the variability and median stand counts in canola in a monocrop and canola in a production crop production method. The monocrop canola shows a wider range of values than the companion crop method and a slightly lower average plant count.

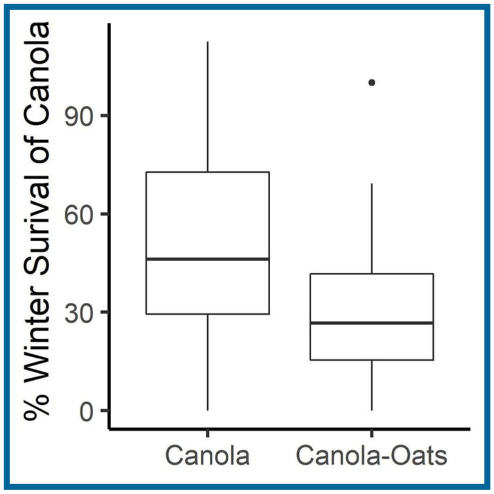


Figure 2. Box plot demonstrating the differences in winter survival between the monocrop winter canola and the companion cropped winter canola. While there was substantial variation in both groups, the monocrop winter canola had a significantly higher winter survival at 51% compared to the companion cropped winter canola at 34%.

Single High-Rate Compost Application in Wheat with Winter Pea Rotation: A Long-Term Study

CAROL MCFARLAND[1], RACHEL ZUGER[1], MARK THORNE[1], NICOLE TAUTGES[2], JENNIFER REEVE[3], EARL CREECH[3], AND IAN BURKE[1]
[1]WASHINGTON STATE UNIVERSITY; [2]UNIVERSITY OF CALIFORNIA-DAVIS; [3]UTAH STATE UNIVERSITY

A long-term compost study site was established at the Washington State University Wilke Research Farm in Davenport, Washington. The study was established in a no-till dryland wheat-based field site on silt loam soil. The site receives an average of 13.28” of annual precipitation. In fall 2016, municipal compost from Spokane, WA, was surface-applied at one-time rates of 0, 5, 25, and 50 tons/ac dry matter. The compost had a pH of 7.5, and a complete nutrient analysis was performed on the compost (Table 1). In 2017 and 2018, a positive control treatment was included where synthetic fertilizer (46-0-0-0 & 16-20-0-13) was applied at planting to winter wheat at a rate of 100 lb/ac nitrogen, 20 lb/ac sulfur, and 33 lb/ac phosphorus.

Nutrient and moisture differences were most pronounced at the 50 tons/ac rate of compost treatment level. In fallow, soil P, K, OM, and moisture were higher with 50 tons/ac compost treatment three years after application.

Figure 1. Wilke farm field site in Davenport, WA with winter wheat and winter peas growing in the spring 2019

Table 1. Fertilizer equivalent of nutrients added with increasing rates of compost.

Compost Rate	**Nutrients added with compost by treatment rate**												
	Org. Matter	*Org. C*	*Tot. N*	*NH_4*	*NO_3*	*P_2O_5*	*K_2O*	*Ca*	*Mg*	*S*	*B*	*Zn*	*Fe*
tons/ac	lbs/ac*												
5	5270	2700	177	14	0.0	120	91	280	47	6	0.3	2	175
25	28985	14850	974	28	0.1	660	501	1540	259	12	0.6	4	349
50	57970	29700	1947	57	0.2	1320	1001	3080	517	23	1.3	8	698

**Converted from dry weight nutrient analysis of compost as provided by Soiltest farm consultants*

Wheat yield was positively correlated to soil organic matter and boron from from 15 90 cm soil depths. Wheat yield and mid-season crop canopy was highest at the 50 tons/ac compost rate with no difference in yield at the 25 ton/ac compost rate. No difference was observed in wheat yield between synthetic fertilizer and 50 tons/ac compost in the winter wheat/chem fallow rotation in 2018 or 2019. Winter wheat yield was higher with 50 ton/ac compost in winter wheat – fallow – winter pea – fallow rotation. Continuing work includes soil enzyme testing, and analysis of microbial biomass.

Table 2. Winter wheat yield (cv. ‘Otto’) in bu/ac by compost treatment and crop rotation at Wilke Farm from 2017-2019

	Soft White Winter Wheat Yield							
	————————— Year —————————							
	2017		*2018*		*2019*		*2019*	
	Wheat-Fallow						Wheat-Fallow-Pea-Fallow	
	————————— Bu/A—————————							
0 tons ac^{-1} DM compost	94	*b*	43	*c*	40	*b*	53	*cd*
Synthetic Fertilizer	-		74	*ab*	46	*ab*	34	*d*
5 tons ac^{-1} DM compost	104	*ab*	52	*bc*	52	*a*	56	*bc*
25 tons ac^{-1} DM	112	*a*	67	*a*	54	*a*	60	*abc*
50 tons ac^{-1} DM	116	*a*	72	*a*	55	*a*	84	*a*
Farm average	87		72		70		70	

Winter Pea: Long-Term Cropping Systems Research in Washington's Drylands

Bill Schillinger[1], Ron Jirava[2], John Jacobsen[1], Steve Schoftstoll[1], Jeremy Hansen[3], and Tim Paulitz[3]
[1]Dept. of Crop and Soil Sciences, WSU Lind; [2]Ritzville farmer, [3]USDA-ARS, Pullman

Inserting a pulse crop into wheat-based rotations has rotational benefit on the subsequent wheat which has been well documented in numerous studies around the world. With symbiotic bacteria, pulses fix atmospheric nitrogen adequate for their needs. Winter pea (WP) is a pulse crop that was harvested on approximately 12,000 acres in the PNW drylands in 2019.

We are currently in the 10th year of long-term experiment at the Ron Jirava farm west of Ritzville, WA (Photo 1). The objective of the experiment is to compare two 3-year crop rotations. These rotations are: (i) WP-spring wheat (SW)-fallow versus (ii) winter wheat (WW)-SW-fallow. Experimental design is a randomized complete block with four replications. All phases of both rotations are present every year for a total of 24 individual plots.

Photo 1. Winter pea planted deep into fallow in a long-term study near Ritzville, WA. Adequate seed-zone soil moisture for germination and seedling emergence is not a problem as winter pea have excellent seedling emergence from deep planting depth. Bill Schillinger photo.

Winter pea can tolerate imozamox herbicide used in the Clearfield® wheat production system. In fact, imozamox herbicide can be applied in-crop to WP for weed control. From 2011 to 2016, only the non-soil-residual herbicides Bentazon and MCPA Amine were used for broadleaf-weed in WP. Since 2017, we have used a half rate of imozamox (i.e., 2 oz/acre Raptor®) for in-crop broadleaf weed control in WP. The grass weed herbicide quizalofop is tank mixed with Raptor to effectively control downy brome and other grass weeds in WP.

From 2011 to 2019, yield of WP ranged from 1514 to 2820 lbs/acre and averaged 2286 lbs/acre (Table 1). Winter wheat grain yield over the 9-yr period ranged from 50 to 87 bu/acre for an average of 73 bu/acre (Table 1). Spring wheat grain yield was significantly greater following WP versus following WW in 2013 and 2015 but in other years there were no treatment differences (Table 1). The long-term average SW grain yield of 34 bu/acre following WP was not statistically different from the average SW yield of 33 bu/acre following WW (Table 1). Spring wheat yields have been numerically, but not significantly, lower following WP versus WW since we started using the soil-residual herbicide imazamox for weed control in WP in 2017. Although the 2 oz/acre rate of Raptor used is only half of that recommended for WP in a 4-year WP-F-WW-F rotation, in our study SW was planted 11 months after Raptor application, not the 16-month period from Raptor application to WW planting in the WP-F-WW-F rotation. Imazamox-tolerant SW varieties have recently been released and these are now used in the experiment beginning in 2020.

Table 1. Grain yield of winter wheat (WW) and winter pea (WP), as well as the subsequent yield of spring wheat (SW) following both WP and WW over a 9-year period at Ritzville, WA.

	Grain yield									
Crop	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**Avg.**
	Winter crop									
Winter pea (lb/ac)	1958	2820	2086	------ [a]	1514	2529	2730	2154	2493	2286 [b]
Winter wheat (bu/ac)	77	85	87	50	63	73	79	82	65	73
	Spring crop [c]									
SW after WP (bu/ac)		30	45a	16	34a	47	33	42	26	34
SW after WW (bu/ac)		32	40b	14	25b	46	34	43	33	33
	Crop-year precipitation [d]									
	inches									
	13.0	11.6	12.6	10.1	10.3	14.6	17.3	14.4	12.6	12.9

[a] WP was winter killed in 2014 and replanted to Banner edible spring pea, which yielded 775 lb/ac.

[b] Winter pea average is for eight years (i.e., 2014 not included).

[c] ANOVA is for SW only. Within-column means followed by a different letter are significantly different at $p < 0.05$.

[d] Crop-year precipitation at site from Sept. 1 – Aug. 31.

Finally, Drs. Hansen and Paulitz are obtaining novel soil health, soil microbiology, and soil microbiome data from this long-term WP study. We hope to have these data available for publication in 2021. A full report of the first six years of the experiment (2011-2016) is available at this link: https://www.frontiersin.org/articles/10.3389/fevo.2017.00043/full

Development of Turf-type *Poa pratensis* L. Germplasm for Seed Production Without Field Burning and the New Washington State University Grass Breeding and Ecology Farm and Program*

WILLIAM JOHNSTON[1], RICHARD JOHNSON[1], CHARLES GOLOB[1], KATHLEEN JOHNSON[2], MATTHEW NELSON[3], GWEN STAHNKE[4], ELIZABETH GUERTAL[5], JONATHAN SCHNORE[1], AND MICHAEL M. NEFF[1]
[1]DEPT. OF CROP AND SOIL SCIENCES, WSU; [2]JACKLIN SEED BY SIMPLOT; [3]GRIGG BROTHERS; [4]WALLA WALLA COMMUNITY COLLEGE; [5]AUBURN UNIVERSITY

Open-field burning of Kentucky Bluegrass (*Poa pratensis* L.) post-harvest residue, which maintains grass seed yield and stand longevity, has been eliminated in Washington and is restricted in Idaho and Oregon, USA. Our objective was to develop Kentucky bluegrass germplasm that has sustainable seed yield without field burning while maintaining acceptable turfgrass quality for use as an amenity grass. From the USDA/ARS Poa pratensis L. Plant Introduction (PI) collection, 228 accessions were evaluated in a field trial and a core collection was developed. This collection was then evaluated in seed production and turfgrass trials and those possessing both good seed yield without field burning and turfgrass quality were identified and planted in a space-plant nursery at Pullman, WA. The eight PI accessions and two commercial cultivars checks were evaluated over a 2-year period and individual plants were reselected within each accession, or check, with the highest seed weight, highest seeds panicle-1, highest panicle number area-1, and highest seed yield. Turfgrass plots were established in 2006, 2009, and 2010 at Pullman, WA, Auburn, AL, and Puyallup, WA, respectively. Seed production plots (irrigated and non-irrigated) were established at Pullman in 2007. Selection for seed yield components had a variable response and seed yield was more dependent on accession. PI 368241, selection panicles area-1, and Kenblue, selection seeds panicle-1, had the best sustainable (four harvests) seed yield without field burning in both non-irrigated and irrigated seed production plots. Both had fair turfgrass quality, whereas PI 371775, selection seeds panicle-1, had good turfgrass quality while maintaining good seed yield with irrigation. These selections have been harvested for seed increase (2012-2014). After seed increases were harvested, Washington State University moved the old Turfgrass Agronomy farm to a new site. The new Grass Breeding and Ecology

Figure 1. The new Washington State University Grass Breeding and Ecology Farm site layout (Top). A view of the farm site taken from the northeast corner looking southwest on January 24th 2020 (Middle). A view from in front of the farm buildings in the southwest corner looking northeast on May 19th, 2020 (Bottom).

Farm is now located adjacent to USDA/ARS Plant Introduction in Pullman WA with Dr. Michael M. Neff as the research lead (Fig. 1). We are now performing Plant Variety Protection (PVP) trials (2019/2020) followed by a PVP application for the selection from Kenblue, currently being called Son-of-Kenblue #1 (SOK #1). The new Grass Breeding and Ecology Program focuses on breeding native and non-native grasses including Kentucky Bluegrass (including hybrids with other *Poa sp*.), Western Wheatgrass (*Pascopyrum smithii*), Prairie Junegrass (*Koeleria macrantha*), Tufted Hairgrass (*Deschampsia cespitosa*) and Teff (*Erogrostis tef*). Breeding characteristics, which vary depending on species, include speed of germination, aggressiveness in growth, yield in dryland and irrigated production systems, drought tolerance, turf quality, mowing tolerance, color and ornamental value.

*This abstract was modified from the following publication: Johnston W, Johnson R, Golob C, Dodson K, Nelson M, Stahnke G and Guertal E. (2015) Development of Turf-type Poa pratensis L. Germplasm for Seed Production without Field Burning. Athens Journal of Sciences 2 (1) 9-16 doi=10.30958/ajs.2-1-1

Winter Triticale: Long-Term Cropping Systems Research in Washington's Wheat-Fallow Drylands

BILL SCHILLINGER[1], RON JIRAVA[2], DAVE ARCHER[3], JOHN JACOBSEN[1], AND STEVE SCHOFSTOLL[1]
[1]DEPT. OF CROP AND SOIL SCIENCES, WSU; [2]RITZVILLE FARMER; [3]USDA-ARS, MANDAN, NORTH DAKOTA

Triticale is annually grown worldwide on more than 10 million acres with a total grain production of 15 million tons. About 90% of triticale is produced in Europe and used mostly as feed grain for livestock. Triticale is currently grown annually on about 9200 acres in Washington. A 9-year dryland cropping systems project was conducted from 2011-2019 on the Ron Jirava farm near Ritzville to compare winter triticale (WT) with soft white winter wheat (WW) for grain yield, grain yield components, straw production, soil water dynamics, and effect on the subsequent spring (SW) wheat crop. Crops were grown in three rotations: (i) a 3-year rotation of WT-SW-no-till summer fallow (NTF) (ii) a 3-year rotation of WW-SW-undercutter tillage summer fallow (UTF) and (iii) a 2-year WW-UTF rotation. Grain yields average over the nine years were 87, 76, and 70 bu/acre (all expressed as 60-pound bushels) for WT, 3-yr WW, and 2-yr WW, respectively (Table 1, Photo 1). Winter triticale used slightly less water that WW (p=0.019). There were no differences in straw weight between WT and WW (see next abstract). Winter wheat produced considerably more stems than WT (p< 0.001), but this was compensated by individual stem weight of WT being 60% heavier than that of WW ((p<0.001). Spring wheat yield averaged 36 vs 34 bu/acre after WT and WW, respectively (p=0.022). The market price for triticale grain was always less than that for wheat. However, WT produced an average of 14 and 24% more grain than 3-yr and 2-yr WW, respectively, and provides rotation benefits. Given average crop prices over the 9-year period, a detailed economic analysis showed that the WT rotation was less profitable than the WW rotations. While the WT rotation provided some risk reduction benefits, these could not overcome the effects of reduced profitability.

Photo 1. Winter triticale (WT) grown in individual 30 x 500 ft (0.34 acre) plots at the long-term cropping systems experiment on the Ron Jirava farm near Ritzville, WA. Grain yield of this WT was 82 bu/acre. Over nine years, grain yield of WT ranged from 63 to 111 bu/acre and averaged 87 bu/acre. Yield is expressed in 60-pound bushels.

Table 1. Grain yield of winter triticale and 3-yr and 2-yr winter wheat for nine years and averaged over years at Ritzville, WA. Note: both winter wheat and winter triticale grain yield are expressed in 60-pound bushels.

	2011	2012	2013	2014	2015	2016	2017	2018	2019	9-yr avg.
Crop	Grain yield (bu/ac)									
Winter triticale	104 a	75	82 a	65	63 a	111 a	92 a	99 a	87 a	87 a
Winter wheat (3-yr)	73 b	79	81 a	55	56 ab	94 b	82 b	88 b	74 b	76 b
Winter wheat (2-yr)	75 b	75	63 b	55	47 b	94 b	78 b	74 c	69 b	70 c
Significance (*p*-value)	0.007	ns (0.34)	< 0.001	ns (0.18)	0.012	0.020	< 0.001	< 0.001	< 0.001	< 0.001
Tukey's HSD (0.05)	21	9	9	17	11	15	6	9	8	3

Winter Triticale Does Not Produce More Straw than Winter Wheat

Bill Schillinger[1], Ron Jirava[2], John Jacobsen[1], and Steve Schofstoll[1]
[1]Dept. of Crop and Soil Sciences, WSU Lind; [2]Ritzville farmer

There are many reports in the world literature that winter triticale (WT) produces more straw than winter wheat (WW). Results from some studies suggest that WT produces twice as much straw as WW. However, these reports have been largely based on visual observations and rarely quantified. Winter triticale grows taller than WW and farmers tend to cut WT straw at harvest at a greater height than for WW. Visually, it certainly appears that WT produces much more straw than WW; but is this correct?

In a long-term cropping systems study on the Ron Jirava farm near Ritzville, we compared a 3-year WT-spring wheat (SW)-fallow (F) rotation with 3-yr WW-SW-F and 2-yr WW-F rotations (see next abstract). For WT and WW in both 3-yr and 2-yr rotations, we counted the number of grain-bearing heads from randomly selected 1-yard-long row sections in each plot just prior to grain harvest from 2015-2019 (Photo 1). The entire aboveground portion of plants from these same 1-yard-long row sections was then hand clipped and collected. Plants were then placed in a low humidity building for two weeks or more then weighed. Kernels per head was calculated based on number of heads/ft2 and 1000-kernel weight after passing heads through a hand-fed thresher and then counting kernels in an automated kernel-counting devise. Straw production was determined by subtracting the weight of the grain from the whole aboveground plant weight.

Photo 1. Early-planted winter wheat (WW, left) and early-planted winter triticale (WT, right) ripe for cutting at the long-term cropping systems experiment near Ritzville, WA. The consistently higher grain yield achieved by WT was due to greater number of kernels per head and heavier kernel weight despite having much fewer heads/ft^2 compared to the WW. Bill Schillinger photo.

There were no statistical differences in the weight of WT straw/ft2 compared to 3-yr and 2-yr WW. The 3-yr WW, however, produced a much greater quantity of straw than did 2-yr WW (Table 1). There were huge differences between WT and WW in the number of stems/ft2 ($p<0.001$) and individual stem weight ($p<0.001$, Table 1). Winter triticale produced an average of only 26 stems/ft2 compared to 45 and 37 stems/ft2 for 3-yr and 2-yr WW, respectively. Individual stems of WT were much thicker and heavier than those of WW with individual stem weight of 2.36 g for WT compared to 1.47 g for 3-yr WW and 1.51 g for 2-yr WW (Table 1). The 3-yr WW always produced significantly more stems/ft2 than 2-yr WW (Table 1).

The thick WT stems that weighed 60% more than those of WW visually masked the fact that WT had far fewer stems. In our study, we consistently found no differences in quantity of straw produced between WT and WW.

Table 1. Straw weight, stem number and stem weight for winter triticale and winter wheat averaged over five years (2015-2019) near Ritzville, WA.

	Straw wt. (lb/ac)	Stems/ft^2	Wt./stem (g)
Winter triticale (3-yr)	6496 ab	26 c	2.36 a
Winter wheat (3-yr)	6712 a	45 a	1.47 b
Winter wheat (2-yr)	5794 b	37 b	1.51 b
Significance (*p*-value)	0.010	< 0.001	< 0.001
Tukey's HSD (0.05)	792	5	0.16

Early versus Late Planting Dates for Winter Triticale and Winter Wheat at Lind

BILL SCHILLINGER, JOHN JACOBSEN, STEVE SCHOFSTOLL, AND BRUCE SAUER
DEPT. OF CROP AND SOIL SCIENCES, WSU LIND

A 5-year field study was conducted during the 2015 to 2019 crop years at the WSU Lind Dryland Research Station to determine early versus late planting date effects on winter triticale (WT) and winter wheat (WW) grain yield. Late planting of WW in mid-to-late October is well known to reduce grain yield by at least 35% compared to WW planted in late August-early September. On the other hand, farmers and researchers had observed that late-planted WT appeared to have less yield drag compared to early-planted WT. Could WT possibly be a better alternative than WW in dry years when early planting deep into carryover soil moisture in fallow is not possible and farmers must wait until the onset of rain in mid-October or later to establish their crops?

Crop-year (Sept. 1 to Aug. 31) precipitation during the study period ranged from 7.61 to 14.78 inches and averaged 11.21 inches (Table 1). Experimental design was a randomized complete block and treatments were replicated six times for a total of 24 plots. Treatments were: (i) early-planted WT; (ii) early-planted WW; (iii) late-planted WT; and (iv) late-planted WW. All treatments were seeded into ground that had been left fallow for at least 13 months. Individual plot size was 8 x 100 feet. Early-planted WT and WW were sown on the same day during the last week of August at a rate of 13 seeds/ft2 with a deep-furrow drill. Late-planted WT and WW were sown shallow in mid-October at a rate of 23 seeds/ft2 with a hoe-opener drill with 4-inch paired rows on 12-inch row spacing. The WT variety ‘Trimark 099’ and WW variety ‘Otto’ were used every year. All seed was treated with a broad-spectrum fungicide + insecticide for wireworm control. Satisfactory plant stands were achieved for all four treatments in all five years.

Early WT produced numerically greater yield that early WW every year and significantly greater yield in two years as well as the 5-yr average (p<.0001). Late WT and WW produced significantly lower yield than their early-planted counterparts in three years as well as the 5-yr average (p<.0001, Table 1). Late WT significantly out yielded late WW in only one year, but the 5-yr average yield difference was highly significantly different (p<.0001). The largest (32%) grain yield advantage of early WT versus early WW was in 2017 (Table 1) with three consecutive days of 90 to 950 F air temperatures in late May when early WW was at its peak of flowering whereas flowering of early WT was completed by that date. A somewhat similar situation occurred in 2018 which resulted in early WT producing 21% more grain than early WW.

To summarize this experiment over the five years:

- Early WT produced 15% more grain yield than early WW.
- Late WT produced 16% more grain yield than late WW.
- Early WT produced 32% more grain yield than late WT.
- Early WW produced 32% more grain yield than late WW.

The 15% yield increase of early WT over early WW is similar to the 9-yr WT cropping systems study at Ritzville (see report on page 36). The grain yield of both late WT and late WW lagged their early-planted counterparts by an average of 32%. These data reinforce the long understand fact that WW (and now understood for WT) must be planted in late August-early September to achieve optimum yield potential.

Table 1. Grain yield of early- and late-planted winter triticale (WT) compared to early- and late-planted winter wheat (WW) for five years at Lind, WA. Early planting was the last week in August and late planting was mid-October. Seeding rate for both WT and WW was 13 seeds/ft^2 for early planting and 23 seeds/ft^2 for late planting.

	2015	2016	2017	2018	2019	5-yr avg.
Crop	Grain yield (lbs/acre)					
Early-planted triticale	1775 a	3795 a	5475 a	5095 a	3455 a	3920 a
Late-planted triticale	1575 ab	3775 ab	2805 c	3005 c	2235 b	2680 c
Early-planted wheat	1745 ab	3345 ab	4070 b	4210 b	3250 a	3325 c
Late-planted wheat	1535 b	3320 b	2425 c	2235 d	1750 b	2250 d
Significance (*p*-value)	0.047	0.012	< 0.001	< 0.001	< 0.001	< 0.001
	Crop-year precipitation (in.)[†]					
	7.61	12.66	14.78	12.20	8.79	11.21

[†] Crop-year precipitation at Lind Sept. 1 – Aug. 31.

Part 2. Pathology, Weeds, and Insects

Downy Brome Control in Winter Wheat

JOAN M. CAMPBELL AND TRACI A. RAUCH
DEPT. OF PLANT SCIENCES, UI

Two studies were established to evaluate downy brome control with Aggressor in CoAXium Axium 'Fusion AX' winter wheat and with Osprey Xtra combined with Zidua in 'Brundage96' winter wheat near Moscow, ID. Co-Axium winter wheat was selected by mutagenesis to be tolerant to the non-selective herbicide Aggressor. The plots were arranged in a randomized complete block design with four replications per treatment. All herbicide treatments were applied using a CO2 pressurized backpack sprayer (Table 1). The Aggressor study was oversprayed on May 13, 2019 with Huskie at 0.19, Starane Flex at 0.04, and Orion at 0.32 lb ai/A for broadleaf weed control and Nexicor at 0.3 lb ai/A for stripe rust control. Crop injury and downy brome control were evaluated visually during the growing season. The Aggressor and Osprey Xtra studies were harvested at crop maturity with a small plot combine on August 5 and 20, 2019, respectively.

Table 1. Application and soil data.

	Aggressor study		Osprey Xtra study	
Winter wheat seeding date	10/12/18		10/16/18	
Application date	4/23/19	5/11/19	10/17/18	5/4/19
Growth stage				
Winter wheat	3 leaf	2 tiller	postplant pre	2 tiller
Downy brome (BROTE)	1 tiller	3 tiller	pre	2 tiller
Solution volume (gpa)	15	15	10	10
Pressure (psi)	38	38	34	34
Speed (mph)	3	3	3	3
Nozzle size	11002	11002	110015	110015
Air temperature (F)	56	82	66	73
Relative humidity (%)	77	25	32	32
Wind (mph, direction)	2, W	3, S	3, W	2, W
Dew present?	yes	no	no	no
Cloud cover (%)	100	10	0	0
Next rain occurred	5/17/19	5/17/19	11/2/18	5/17/19
Soil moisture	wet	dry	dry	adequate
Soil				
temperature at 2 in (F)	50	76	55	68
pH	4.5		4.5	
OM (%)	2.6		3.2	
CEC (meq/100g)	13.3		12.5	
Texture	loam		silt loam	

In the Aggressor study, all treatments injured winter wheat 0 to 2% but there were no differences in phytotoxicity among treatments (Table 2). All treatments, except Zidua alone, controlled downy brome 92 to 99%. Grain yield tended to be lowest for the untreated check but was not statistically different among treatments. Grain test weight did not differ among treatments including the untreated check.

Table 2. Winter wheat response and downy brome control with Aggressor near Moscow, ID in 2019.

				Winter wheat		
Treatment[1]	Rate	Application timing[2]	Downy brome control[3,4]	Injury[3,4]	Yield[4]	Test weight[4]
	lb ai/A		%	%	lb/A	lb/bu
Zidua	0.065	2 leaf	56	0	3510	60.4
Aggressor + NIS	0.055 + 0.25% v/v	2 leaf	99	2	4000	61.0
PowerFlex	0.0164	2 leaf	97	2	3829	60.0
Zidua + Aggressor +NIS	0.065 0.055 + 0.25% v/v	2 leaf 2 tiller	99	0	3715	60.9
Aggressor + NIS	0.055 + 0.25% v/v	2 tiller	99	1	3604	59.5
Aggressor + NIS	0.069 + 0.25% v/v	2 tiller	99	0	4087	60.6
Aggressor + NIS	0.083 + 0.25% v/v	2 tiller	99	0	4124	61.4
Aggressor + MSO	0.055 + 1% v/v	2 tiller	99	1	3938	60.5
Aggressor +NIS + UAN	0.055 + 0.25% v/v + 20% v/v	2 tiller	99	0	4077	60.9
PowerFlex	0.0164	2 tiller	94	0	3950	60.4
Osprey Xtra	0.0178	2 tiller	92	0	3744	59.6
Untreated check	--	--	-	--	3239	59.6
LSD (0.05)			10	NS	NS	NS
Density (plants/ft^2)			5			

[1] PowerFlex treatments were applied with a non-ionic surfactant at 0.25% v/v and ammonium sulfate at 1.5 lb ai/A. Osprey Xtra was applied with a non-ionic surfactant at 0.5% v/v and urea ammonium nitrate at 4 pt/A.

[2] Application timing based on winter wheat growth stage.

[3] Evaluation date June 19, 2019.

[4] Some plots in Rep 4 were not included due to winter flood.

In the Osprey Xtra study, all treatments injured winter wheat 0 to 11% but did not differ among treatments (Table 3). Downy brome control was best with Zidua combinations and Osprey plus Huskie and Bromac (90 to 99%) but did not differ from Zidua alone (88%). Grain yield tended to be lowest for the untreated check but did not differ among treatments. Grain test weight was lowest for the untreated check.

Table 3. Winter wheat response and downy brome control with Osprey Xtra combined with Zidua near Moscow, ID in 2019.

					Winter wheat	
Treatment[1]	Rate	Application timing[2]	Downy brome control[3]	Injury[3]	Yield	Test weight
	lb ai/A		%	%	lb/A	lb/bu
Zidua	0.08	preemergence	88	0	6852	60.8
Zidua + Osprey Xtra	0.08 0.0178	preemergence 2 tiller	99	9	6295	60.6
Zidua + Osprey Xtra + Huskie	0.08 0.0178 0.217	preemergence 2 tiller 2 tiller	98	6	6846	61.3
Zidua + Osprey Xtra + Huskie + Bromac	0.08 0.0178 0.217 0.5	preemergence 2 tiller 2 tiller 2 tiller	98	7	6270	60.5
Zidua + Osprey + Huskie + Bromac	0.08 0.0134 0.217 0.5	preemergence 2 tiller 2 tiller 2 tiller	98	5	6486	60.8
Osprey Xtra	0.0178	2 tiller	72	2	6418	60.1
Osprey Xtra + Huskie	0.0178 0.217	2 tiller 2tiller	76	5	6829	60.7
Osprey Xtra + Huskie + Bromac	0.0178 0.217 0.5	2 tiller 2 tiller 2 tiller	78	8	6388	60.4
Osprey + Huskie + Bromac	0.0134 0.217 0.5	2 tiller 2 tiller 2 tiller	90	11	6462	60.7
Untreated check	--	--	-	-	5634	59.2
LSD (0.05)			11	NS	NS	0.7
Density (plants/ft^2)			5			

[1] All postemergence treatments were applied with a non-ionic surfactant at 0.25% v/v and urea ammonium nitrate at 5% v/v.

[2] Application timing based on winter wheat growth stage.

[3] Evaluation date June 7, 2019.

Effect of Cultural Management on Russian Thistle Suppression

Nicholas G. Genna, Jennifer A. Gourlie, and Judit Barroso
Columbia Basin Agricultural Research Center, OSU

No-till farming relies on herbicides to control weeds. Monoculture winter wheat production and ubiquitous glyphosate use in this region is selecting for herbicide resistance in major agronomic weeds. Russian thistle (Salsola tragus) is one weed that has recently been identified as glyphosate resistant in Oregon, Montana, and Washington. Farmers in the PNW need new tools to control Russian thistle and slow the spread of glyphosate resistance. In this research, we explore cultural weed management as a tool to suppress Russian thistle.

In 2018 and 2019, experiments with spring barley (SB) and spring wheat (SW) were established in a completely randomized split-plot block design with four replications in Moro, OR and Pendleton, OR. The cultural management treatments in both crops included seeding in 7- or 14-inch row spacings and at 65 or 125 lb/ac (Photo 1). Russian thistle seed (20 seeds/ft^2) was spread within each subplot (150 ft^2) before seeding crops to provide abundant weed pressure in crop. Russian thistle density was determined in spring and before harvest in five random areas (5 ft^2) within subplots. Following harvest and determination of crop yield, five Russian thistle plants were randomly selected within subplots to determine mean seed number per plant.

Russian thistle density was significantly affected by year, site and crop. In 2018, germination was higher in Pendleton (0.51 plants ft^2) than in Moro (0.19 plants ft^2) and higher in SW (0.39 plants ft^2) than in SB (0.32 plants ft^2). Both crops suppressed Russian thistle during the growing season in Pendleton but not in Moro. In Pendleton, Russian thistle plant density reduced by 65% in SB and 36% in SW. Row spacing also affected Russian thistle germination and mortality. At harvest, Russian thistle density was 0.09 and 0.21 plants ft^2 for narrow and wide inter-row spacing treatments in SB and 0.27 and 0.4 plants ft^2 in SW, respectively. Results in 2018 indicate that SB was more competitive than SW to suppress Russian thistle, although, the level of crop competitiveness depended on site. In 2019, in Pendleton, Russian thistle density at harvest (0.08 plants ft^2) was two times higher than in Moro (0.04 plant ft^2). Both crops, at both sites, suppressed Russian thistle, but the suppression effect was higher in Moro (29% on average) than in Pendleton (20% on average) in 2019. In Moro, where the crop was more competitive in 2019, Russian thistle germination was two times higher in wide inter-row spacing treatments compared to narrow inter-row spacing treatments. Crop density did not effect Russian thistle germination in 2019.

Russian thistle seed production per plant was significant ($P < 0.05$) with the crop and the site and marginally significant ($P < 0.1$) with their interaction (Crop × Site). On average for both years, each Russian thistle plant produced 1336 and 557 seeds in SW and SB in Moro and 762 and 670 seeds in SW and SB in Pendleton. However, Russian thistle seed production was not significantly affected by row spacing or crop density in either year, indicating that crop type seems to be more important than the seeding pattern to suppress Russian thistle seeds. We believe this research is a first step towards understanding how cultural management practices can suppress Russian thistle in the PNW.

Photo 1. View of spring wheat plots in Pendleton with a) wide row spacing (14 in) or b) narrow row spacing (7 in).

Fusarium avenaceum and Soluble Aluminum Induce Defense Protein Release from Wild Oat Seeds

PATRICIA OKUBARA[1], RICKY W. LEWIS[2], AND E. PATRICK FUERST[2]
[1]USDA-ARS, WHEAT HEALTH, GENETICS AND QUALITY; [2]DEPT. OF CROP AND SOIL SCIENCES, WSU

Wild oat (*Avena fatua*) can be a major yield-limiting factor in dryland cereal production regions of the Pacific Northwest and in other parts of the world. It competes with wheat and barley in soils undergoing acidification that contain enhanced soluble concentrations of metals, including aluminum (Al). To explore the mechanisms underlying wild oat seed responses to soilborne pathogens and soil metals, comprehensive protein profiles were generated from caryopses (naked seeds without hulls) exposed to the oat seed decay pathogen Fusarium avenaceum isolate F.a.1 and/or sublethal concentrations of Al (400 µM). In these extracts, four proteins accumulated or decreased in response to pathogen infection, three of which were associated with biotic or abiotic stress. Treatment with Al resulted in decreased abundance for four proteins, two of which were annotated as defense/stress proteins. Protein regulation by F.a.1 and Al was complex but in general, Al treatment precluded the impact of F.a.1 on host protein accumulation in caryopses. Protein profiles were also generated from caryopsis leachates, obtained by soaking naked grains in a buffer solution after F.a.1 or water treatment. Proteins associated with developmental processes, defense or stress, and "unknown" functions represented 23%, 19% and 22%, respectively, of all proteins induced by F.a.1 relative to the water control. Proteins involved in cell structure, housekeeping processes and secondary metabolism represented 2-4% of all induced proteins. Additionally, highly abundant fungal proteins were present in the leachates; these mainly included proteins involved in primary metabolism, cellular processes and "hypothetical proteins" of unknown function. Ongoing re-annotation of the hypothetical proteins indicates that many are related to cell wall and serine metabolism. At present, the findings suggest that wild oat seeds mount a defense response to soil pathogens that may be conditioned by soil chemical factors.

Dynamics of Soil Arthropod Communities in Palouse Agroecosystems

DANE C. ELMQUIST AND SANFORD D. EIGENBRODE
DEPT. OF ENTOMOLOGY, PLANT PATHOLOGY AND NEMATOLOGY, UI

The sustainability of Palouse agroecosystems depends on the maintenance of healthy soils. The belowground arthropod communities that inhabit soils are responsible for ecosystem services that benefit agriculture in our region. As Palouse growers transition from traditional cereal production systems to novel systems with more diverse crops and rotations, native soil arthropod assemblages are likely to be affected. The complexity and opacity of soil makes studying the structure and function of soil arthropod communities difficult, so this aspect of soil health is understudied everywhere and has not been investigated for Palouse agroecosystems. Including soil arthropods as biological indicators can provide a more complete understanding of the ecological processes that characterize healthy soils.

Figure 1. Berlese funnel used for soil arthropod extraction. A heat and moisture gradient drives arthropods down the funnel into a cup filled with ethanol to preserve them for identification.

As part of the ongoing Landscapes in Transition project (LIT), we have been studying the responses of soil arthropod communities to crop diversification. In 2018 and 2019, soil arthropod communities were evaluated across three different crop rotations at two sites in different Palouse agroecological zones. Rotations included "business-as-usual" rotations (BAU), a cover crop rotation, and a winter pea rotation at each site. Arthropods were sampled (Fig. 1) after spring planting, mid-way through the growing season, and post-harvest in autumn. To date, we have collected over 500 community samples and characterized over 30,000 arthropods. Initial results indicate that crop diversification influences soil arthropod communities with implications for soil and crop health.

At our rotation trial in St. John, WA, soil arthropods in fallow and winter pea had different community structures (Fig. 2a, 2c). Compared to fallow, winter pea increased the abundance of predator and detritivore arthropods in soil communities (Fig. 2b, 2d). Augmenting predator communities improves control of soil pests. An increase in detritivores improves nutrient cycling and facilitates healthy microbial communities. On the other hand, the winter pea rotation at St. John also had the highest number of soil-dwelling arthropod pests compared to BAU and spring cover crop rotations. Thus, alternative crops and rotations can have complex effects on soil fauna.

To examine possible effects of previous crops (legacy effects), we evaluated arthropod abundance and diversity in winter wheat in 2019 following three different crops at our trial in Genesee, ID. Soil arthropod community diversity was lowest in winter wheat following winter pea and abundance was greatest after chickpea in the BAU rotation (Fig. 3). In contrast, legacy effects on soil arthropods were not evident at St. John. Site differences in legacy effects in winter wheat could reflect differences soil ecological processes with implications for the long-term effects of rotation management strategies on soil health.

Results from this ongoing research will contribute to refinement of best-management practices for the diversification and intensification of cropping systems across the Palouse. Developing targeted agronomic strategies for managing soil arthropod communities in Palouse agroecosystems will result in important advances for sustainable agriculture in our region and beyond.

LIT is funded through award #2017-68002-26819 from the USDA NIFA (www.pnwlit.org/)

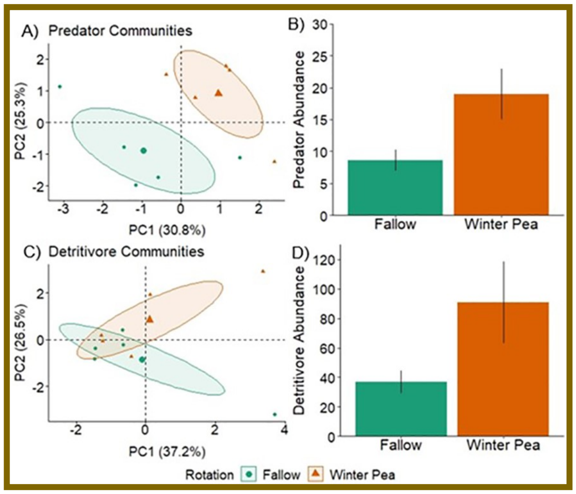


Figure 2. Arthropod communities (A & C) and abundance of key functional groups (B & D) in winter pea and fallow at St. John, WA (mean +/- se). Each point in A and C represents a soil arthropod community and the values PC1 and PC2 are composites based on all of the species present. The extent of overlap of the ellipses in A and C indicates the similarity of the community types.

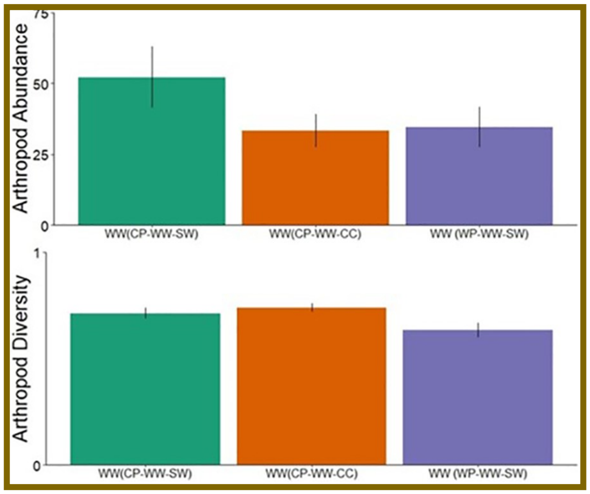


Figure 3. Belowground arthropod abundance (top) and diversity (bottom) in winter wheat following three different crops (mean +/- se). Diversity here is a measure based on how many species are present and how evenly they are distributed. Abbrev: WW: Winter wheat; CP: Chickpea; SW: Spring Wheat; CC: Winter cover Crop; WP: Winter Pea. Labels indicate the full rotation.

Population Dynamics of Wheat Root Pathogens Under Different Tillage Systems in NE Oregon

Chuntao Yin[1], Katherine McLaughlin[2], Timothy C. Paulitz[3], Duncan R. Kroese[4], and Christina H. Hagerty[4]
[1]Dept. of Plant Pathology, WSU; [2]Dept. of Statistics, OSU; [3]USDA-ARS, Wheat Health, Genetics and Quality Research Unit, WSU; [4]Columbia Basin Agricultural Research Center, OSU

No-till or direct-seeding can be described as seeding directly into the crop stubble from the previous season without use of tillage. A reduction in tillage can result in many benefits, including increased soil organic matter, increased water holding capacity, and reduced fuel costs. However, the effect of no-till and reduced tillage on crop root disease profiles is poorly understood. To study the effect of tillage on disease dynamics, soil samples were collected from commercial wheat fields representing a wide range of tillage strategies in fall 2016 and fall 2017. Because precipitation might affect soilborne diseases, wheat fields located across a diverse gradient of precipitation zones of the dryland Pacific Northwest were selected. *Fusarium* spp., *Pythium* spp., and *Rhizoctonia* spp. were quantified from soil samples using soil dilution plating and quantitative PCR (qPCR) assays. Results of dilution plating showed that the colony counts of *Fusarium, Pythium,* and *Rhizoctonia* at the genus level were negatively associated with tillage. However, the same patterns were not observed when specific causal agents of *Fusarium, Pythium,* and *Rhizoctonia* that are known to be pathogenic on wheat were quantified with qPCR. Furthermore, precipitation affected the population density of some fungal pathogens (*F. culmorum, P. ultimum,* and *R. solani* AG 8). Within the scope of inference of this study, results of this study indicate that the benefits of adopting reduced tillage likely outweigh potential risk for increased root disease.

Wheat Tolerance to Talinor

JOAN CAMPBELL AND TRACI A. RAUCH
DEPT. OF PLANT SCIENCES, UI

Fertilizers as a carrier or as an adjuvant with grass herbicides can sometimes cause crop injury when combined with Talinor. Application timing is also critical in reducing crop response. Studies were established to evaluate crop tolerance with Talinor herbicide combined with fertilizers alone or as an adjuvant with grass herbicides in ‘Magic’ winter wheat and application timing in ‘Ryan’ spring wheat at the University of Idaho Plant Science Farm near Moscow, ID. These studies were under weed-free conditions. The plots were arranged in a randomized complete block design with four replications and included an untreated check. All herbicide treatments were applied using a CO2 pressurized backpack sprayer calibrated to deliver 10 gpa at 3 mph. Crop injury was evaluated visually during the growing season. Grain was harvested with a small plot combine on August 6 and 21, 2019 in winter and spring wheat, respectively.

In the Talinor plus various fertilizers study, no treatment visibly injured winter wheat (data not shown). Grain yield and test weight did not differ among treatments (Table 1).

Table 1. Winter wheat response with Talinor combined with various fertilizers as carriers near Moscow, Idaho in 2019. (This was under weed-free conditions.)

Treatment[1]	Rate	Yield	Test weight
	lb ai/A	lb/A	lb/bu
Talinor	0.193	6025	62.1
Talinor + urea ammonium nitrate (URAN 32% -McGregor Co.)	0.193 25% v/v	5859	61.4
Talinor + urea nitrogen/methylene urea/triazone urea (NDemand 30L)	0.193 25% v/v	5886	62.0
Talinor + urea nitrogen/triazone urea/methylene urea (Maximum N-Pact)	0.193 25% v/v	5793	62.1
Talinor + urea nitrogen (Stand 12-0-2)	0.193 25% v/v	5838	62.1
Talinor + urea nitrogen/methylene urea/methylene diurea (CoRoN 28-0-0)	0.193 25% v/v	5952	62.1
Talinor + liquified urea	0.193 30% v/v	6223	61.6
Talinor + liquified urea	0.193 50% v/v	6254	62.2
Talinor + liquified urea	0.193 85% v/v	6187	62.0
LSD (0.05)		NS	NS

[1] All treatments were applied with a buffer, sodium bicarbonate (CoAct+), at 0.58 lb ai/A and a nonionic surfactant (R-11) at 0.25% v/v. Trade name of fertilizer is listed in parentheses.

In the Talinor plus grass herbicides with and without UAN (urea ammonium nitrate) study, Talinor alone plus UAN, Osprey Xtra alone or combined with Talinor plus UAN, and Beyond combined with Talinor plus UAN injured winter wheat 4 to 11% at 5 DAT (Table 4). At 10 DAT, Talinor plus UAN and Beyond combined with Talinor plus UAN injured winter wheat 15%. Grain yield and test weight did not differ among treatments (Table 2).

Table 2. Wheat response with Talinor combined with grass herbicides and fertilizer near Moscow, ID in 2019. (This was under weed-free conditions.)

		Wheat injury		Wheat	
Treatment[1]	Rate	5 DAT	10 DAT	Yield	Test weight
	lb ai/A	%	%	lb/A	lb/bu
Talinor	0.193	0	0	6914	61.9
Talinor + UAN	0.193 15% v/v	9	15	6466	61.8
Talinor + Power Flex	0.193 0.0164	0	0	6557	62.0
Talinor + Power Flex + UAN	0.193 0.0164 15% v/v	1	3	6448	61.9
Talinor + Osprey Xtra	0.193 0.0178	2	0	6964	62.3
Talinor + Osprey Xtra + UAN	0.193 0.0178 15% v/v	4	1	6497	61.8
Talinor + Beyond	0.193 0.047	2	4	6259	61.8
Talinor + Beyond + UAN	0.193 0.047 15% v/v	11	15	6632	61.7
Power Flex + UAN + NIS	0.0164 15% v/v 0.25% v/v	0	0	6827	61.8
Osprey Xtra + UAN + NIS	0.0134 15% v/v 0.25% v/v	5	9	6633	61.9
Beyond + UAN + NIS	0.047 15% v/v 0.25% v/v	0	0	7620	62.4
LSD (0.05)		3	1	NS	NS

[1] All treatments were applied with a buffer, sodium bicarbonate (CoAct+), at 0.58 lb ai/A and a nonionic surfactant (R-11) at 0.25% v/v. UAN is urea ammonium nitrate (fertilizer).

In the application timing study, no treatment visibly injured spring wheat (data not shown). Grain yield did not differ among treatments including the untreated check (Table 3). Grain test weight was greater for the untreated check and the joint application time compared to the swollen boot timing.

Table 3. Spring wheat response with Talinor applied at various timings near Moscow, Idaho in 2019. (This was under weed-free conditions.)

Treatment[1]	Rate	Application timing	Yield	Test weight
	lb ai/A		lb/A	lb/bu
Talinor	0.193	2 tillers	5972	63.2
Talinor	0.193	joint	5702	63.4
Talinor	0.193	swollen boot	5850	62.8
Talinor	0.193	visible head (25%)	5716	63.1
Untreated check	--	--	6005	63.4
LSD (0.05)			NS	0.4

[1] All treatments were applied with a buffer, sodium bicarbonate (CoAct+), at 0.58 lb ai/A and a nonionic surfactant (R-11) at 0.25% v/v.

Rhizoctonia Infestation and Root Imaging

KATHRYN A. DOONAN AND ISAAC J. MADSEN
DEPT. OF CROP AND SOIL SCIENCES, WSU

The pathogen, Rhizoctonia spp., poses yield concerns within wheat production, especially with no-till and conservation tillage systems. Rhizoctonia damage often presents with root rot, bare patches, and reduced plant vigor and yield. Root imaging techniques provide a means to investigate the relationship between cropping system, infestation, and potential variety resistance to Rhizoctonia spp. Root imaging allows for the investigation of significant differences between the infested trials and the control trials and allows for observation of the pathogen infestation through time. In this study, variation between rhizoctonia infested wheat varieties and non-infested wheat varieties were observed through both root imaging and final excavation measurements and rating. The varieties Louise (L), SPCB3104 (S), and Lxsyn3104BC2F-613G (LxSyn) were planted in a randomized order within 3 cells on a Lide 700F scanner. (4 replicates of each type, both infested and non-infested) The experiment was run through a two-week window, where the wheat was allowed to emerge, and scans were taken every 4 hours. Each scanner trial was watered regularly and run with a 12-hour grow light interval. After 2 weeks, the scans were ended, and roots were excavated. Measurements were taken on above-ground biomass, root length, and Rhizoctonia damage symptoms.

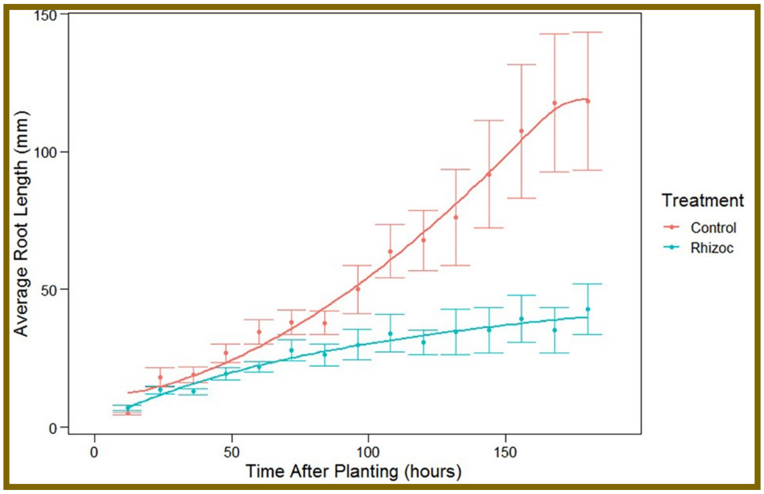


Figure 1. Average Root Length Over Time. Control roots can be seen to growing at faster rates than the roots grown in the presence of Rhizoctonia.

Figure 1 depicts the Rhizoctonia infested trials along with the control trials. These preliminary results show that there is a significant difference in mean root length between control and treated varieties. Root length contributes greatly to the plant's ability to take up both water and nutrients and may be attributed to greater overall plant vigor. While there is a clear difference between growth habit of infested varieties and non-infested varieties on average root length, there was no significant correlation between the separate wheat biotypes and their relative resistance to Rhizoctonia. Currently, further research is being undertaken to assess the potential for variety specific resistance and field management factors that influence the degree of damage Rhizoctonia may inflict. The presence of Rhizoctonia may not be the only determining factor in the amount of damage or yield loss present within the affected field.

Grass and Broadleaf Weed Control in Winter Wheat with Osprey Xtra

JOAN M. CAMPBELL AND TRACI A. RAUCH
DEPT. OF PLANT SCIENCES, UI

A study was established to evaluate rattail fescue, jointed goatgrass, and mayweed chamomile control with Osprey Xtra alone or in combination in winter wheat near Moscow, ID. The plots were arranged in a randomized complete block design with four replications and included an untreated check. All herbicide treatments were applied using a CO_2 pressurized backpack sprayer calibrated to deliver 10 gpa at 32 psi and 3 mph (Table 1). Crop injury and weed control were evaluated visually during the growing season.

Table 1. Application and soil data.

Application date	5/13/2019
Growth stage	
Winter wheat	2 tiller
Rattail fescue	3 tiller
Jointed goatgrass	3 tiller
Mayweed chamomile	2 inch
Air temperature (F)	82
Relative humidity (%)	26
Wind (mph, direction)	2, SW
Cloud cover (%)	100
Next moisture occurred	5/17/2019
Soil moisture	dry
Soil temperature at 2 inch (F)	80
pH	4.9
OM (%)	3.0
CEC (meq/100g)	18.1
Texture	silt loam

At 17 DAT, all herbicide combinations with Osprey Xtra injured winter wheat 5 to 8%, except Huskie alone (Table 2). No visual injury was evident by 33 DAT (data not shown). At 17 DAT, Osprey Xtra combined with Huskie and Bromac controlled rattail fescue 88%. AT 66 DAT, rattail fescue control did not differ among all treatments (94 to 96%). Jointed goatgrass control did not differ

among treatments but tended to be better with Osprey Xtra plus Huskie alone or combined with Bromac. All treatments, except Osprey Xtra alone, controlled mayweed chamomile 94 to 98%.

Table 2. Weed control and winter wheat response with Osprey Xtra combinations in 2019.

			Weed control			
		Wheat[2]	Rattail fescue		Jointed[3]	Mayweed[3]
Treatment[1]	Rate	injury	17 DAT	66 DAT	goatgrass	chamomile
	lb ai/A	%	%	%	%	%
Osprey Xtra	0.0178	2	75	95	68	81
Osprey Xtra + Huskie	0.0178 0.217	0	80	95	85	94
Osprey Xtra + Huskie+ Bromac	0.0178 0.217 0.5	8	88	94	87	97
Osprey Xtra + Huskie+ Starane Flex	0.0178 0.217 0.092	6	80	96	79	97
Osprey Xtra + Huskie+ Widematch	0.0178 0.217 0.188	5	80	95	77	98
LSD (0.05)		4	6	NS	NS	6
Density (plants/ft^2)			10		1	1

[1] All treatments were applied with a non-ionic surfactant at 0.25% v/v and urea ammonium nitrate at 5% v/v.

[2] 17 days after treatment.

[3] 66 days after treatment.

Wheat Soil-Borne Mosaic: Yield Loss and Distribution in the US Pacific Northwest

D. R. KROESE[1], L. SCHONNEKER[1], S. BAG[2], K. FROST[3], R. CATING[4], AND C. H. HAGERTY[1]
[1]DEPT. OF BOTANY AND PLANT PATHOLOGY, OSU; [2]DEPT. OF PLANT PATHOLOGY, UNIVERSITY OF GEORGIA; [3]DEPT. OF BOTANY AND PLANT PATHOLOGY, HERMISTON AGRICULTURAL RESEARCH AND EXTENSION CENTER, OSU; [4]LIPMAN FAMILY FARMS

Soil-borne wheat mosaic virus (SBWMV), the causal agent of Wheat soil-borne mosaic (WSBM) was discovered for the first time in the dryland wheat production zone of the US Pacific Northwest (PNW) in 2008. Current WSBM distribution in the Walla Walla Valley that spans the Oregon/Washington border was documented during 2017 and 2018. Yield loss estimates of rainfed winter wheat were also determined for this growing region. WSBM is more widely distributed in the Walla Walla Valley than was previously estimated. Significant reductions of grain yield (40%), biomass (37%), and heads per area (34%) were documented in association with SBWMV infection in commercial winter wheat fields each year. Test weight was reduced by 2.3% (P=0.08). No significant difference in the number of spikelets per head was observed in association with WSBM. This work is part of an ongoing effort to provide management solutions to WSBM.

Cereal Rust Management and Research in 2019

X.M. CHEN[1,2], K.C. EVANS[1], M.N. WANG[2], J. SPROTT[1], Y. LIU[2], L. LIU[2], Y.X. LI[2], AND J.M. MU[2]
[1]USDA-ARS WHEAT HEALTH, GENETICS, AND QUALITY RESEARCH UNIT; [2]DEPT. OF PLANT PATHOLOGY, WSU; [3]DEPT. OF CROP AND SOIL SCIENCES, WSU

In 2019, wheat stripe rust was accurately forecasted at relatively low levels for the eastern Pacific Northwest (PNW) using prediction models and monitored in fields throughout the crop season, and the disease was the lowest of the last 5 years. As usual, wheat stripe rust was severe in northwestern Washington. Rust updates and advises were provided in a timely manner to growers based on the forecasts and field surveys. As the natural disease pressure was low, we inoculated our field experiments around Pullman to create adequate stripe rust in order to have reliable germplasm screening data. In the artificially inoculated fields, yield losses of 36 percent were observed on the susceptible check and 0-19 percent (average 6 percent) on commercial varieties of winter wheat; and of 33 percent on the susceptible check and 0-12 percent (average 2 percent) on commercial varieties of spring wheat in our experiment fields without fungicide application. There were few commercial fields had significant stripe rust, and rust was controlled by timely application of fungicide in the early crop season. Nationally, wheat stripe rust occurred in 16 states in 2019, fewer than 2017 and 2018, and damage was also less than the previous two years. Barley stripe rust occurred in California, Oregon, Idaho, and Washington. In Washington, barley stripe rust was severe in western Washington, but low in eastern Washington, similar to the previous years. In 2019, up to 40% severity of leaf rust occurred on some winter wheat germplasm lines in our experimental fields in western Washington, but no barley leaf rust was found, which was very different from severe leaf rust situations in the same location in 2015 to 2017. In eastern Pacific Northwest, wheat leaf rust was found in winter wheat nurseries in Central Ferry and in spring wheat nurseries in Walla Walla, Washington, but not found in checked commercial fields. No barley leaf rust was found or reported in eastern PNW. Barley leaf rust appeared only once in eastern PNW in 2017. In 2019, stem rust of wheat was found in experimental fields in Pullman and Central Ferry. From stripe rust samples collected throughout the country, we identified 26 races (3 new) of the wheat stripe rust pathogen and 10 races (2 new) of the barley stripe rust pathogen. In Washington state alone, 25 races (2 new) of the wheat stripe rust pathogen and 8 races (2 new) of the barley stripe rust pathogen were identified. Using whole genome sequencing of the mutant isolates, we identified 62 candidates for avirulence genes in the wheat stripe rust pathogen. We evaluated more than 35,000 wheat, barley, and triticale entries for resistance to stripe rust in fields and about 3,000 of them also in the greenhouse, and provided the data to breeding and other related programs. We collaborated with breeders in pre-releasing, releasing, and registering 15 wheat and 2 barley varieties. We mapped 6 genes for all-stage and high-temperature adult-plant resistance to stripe rust in wheat landrace PI 181410; and mapped 37 (10 new) genes for stripe rust resistance in 616 spring wheat and 52 genes in 857 winter wheat varieties and breeding lines of the US using the genome-wide association study approach. These studies provide the information on which resistance genes deployed in US wheat and how effective of these genes. We tested 33 fungicide treatments in fields for control of stripe rust on both winter and spring wheat; and 24 winter and 24 spring wheat varieties for their yield loss and fungicide response. In 2019, we published 27 journal articles, 5 meeting abstracts, and 10 popular press articles. The results and genetic resources produced from our research have been used to develop stripe rust resistant varieties, registering new fungicides, and guiding rust management.

Wireworm Species Differ in Wheat Plant Damage Under Well-Watered and Drought-Stressed Conditions

XI LIANG[1], ATOOSA NIKOUKAR[2], AND ARASH RASHED[2*]
[1]DEPT. OF PLANT SCIENCES, UI; [2]DEPT. OF ENTOMOLOGY, PLANT PATHOLOGY, AND NEMATOLOGY, UI

Wireworms are the immature stage of click beetles (Col., Elateridae) and one of the major concerns of cereal producers in the Pacific Northwest (PNW). This concern mainly stems from the lack of effective insecticides, which subsequently results in devastating yield losses in severely infested fields. The sugar beet wireworm *Limonius californicus* and the western field wireworm *L. infuscatus* are the two most prevalent species of click beetles in the PNW. To develop effective integrated management approaches, research is needed to understand their ecology, specifically their interactions with the surrounding environment. The objective of the current study was to evaluate and compare feeding damage by these two predominant PNW wireworm species in the presence and absence of water stress. A greenhouse experiment was conducted on potted wheat plants (*Triticum aestivum* L.cv. 'Klasic') infested with either sugar beet or western field wireworm under drought-stressed and well-watered conditions. Our overall results indicated that emergence of wheat plants was not affected by the presence of either wireworm species under well-watered conditions when compared to the nonifested controls ($F_{2,360} = 1.62$, $P = 0.199$). However, under drought stress, the probability of wheat emergence was relatively lower in the sugar beet wireworm compared to the western field wireworm ($F_{2,360}$ = 2.47, P = 0.086). After emergence, wireworm feeding damage was not different between wireworm species under drought stress ($F_{1,190}$ = 0.05, P = 0.830), whereas more damage was associated with the western field wireworm compared to the sugar beet wireworm under well watered conditions ($F_{1,190}$ = 8.37, P = 0.004). Shoot biomass of wheat plants subject to wireworm infestation of either species was not different from the noninfested controls under drought stress ($F_{2,94}$ = 0.02, P = 0.984). However, under well-watered conditions the wheat plants that were exposed to the sugar beet wireworms produced lower aboveground biomass than those exposed to either western field wireworms or non-infested controls ($F_{2,94}$ = 7.71, $P < 0.001$). Our results indicated that a clear knowledge of wireworm species and soil moisture would assist in predicting the extent of damage within a field. Such information would allow for targeted use of preventive cultural and chemical control methods in cereal cropping systems.

Evaluation of Preemergence Herbicides for the Control of Russian-thistle in Chemical Fallow

HENRY WETZEL, DREW LYON, AND MARK THORNE
DEPT. OF CROP AND SOIL SCIENCES, WSU

A trial was established on chemical fallow ground on the Smith Farm near Lind, WA to evaluate timings of preemergence herbicides for the control of Russian-thistle. The objective of the study was to evaluate various herbicides applied preemergence to take some of the selection pressure off of glyphosate and paraquat, the two most common herbicides used to control Russian-thistle postemergence. Glyphosate-resistant Russian-thistle plants have been documented in Washington, Oregon and Montana.

The chemical fallow period followed spring wheat. It was such a dry fall that a burndown application across the trial area was not necessary at the time of the initial application on November 28, 2018. This will be referred to as the late fall application timing. Treatments were applied with a CO2-powered backpack sprayer set to deliver 10 gpa at 48 psi at 2.3 mph. The air temperature was 50°F, relative humidity was 61% and the wind was out of the south at 6 mph. The second application occurred on March 28, 2019, which will be referred to as the late winter application timing. Treatments were applied with a CO2-powered backpack sprayer set to deliver 10 gpa at 56 psi at 2.3 mph. The air temperature was 50°F, relative humidity was 68% and the wind was out of the northeast at 5 mph. In addition, on March 28th, RT-3 + AMS (32 fl oz/A + 17 lb per 100 gallon) was applied over the trial area to control primarily volunteer spring wheat. After May 15th rating date, the trial area was sprayed with RT-3 plus Spray Prep (32 fl oz/A + 2 qts/100 gal) to control the Russian-thistle and tumble mustard. After the June 13th rating date, Russian-thistle plants were hand rouged. After the July 9th rating date, RT-3, 2,4-D LV6, Spray Prep and M-90 (64 fl oz/A + 8.0 fl oz/A + 2.0 qt per 100 gallons + 0.25% v/v) were applied to the entire trial area to control Russian-thistle. Soil at this site is a silt loam with 2.1% organic matter and a pH of 5.9.

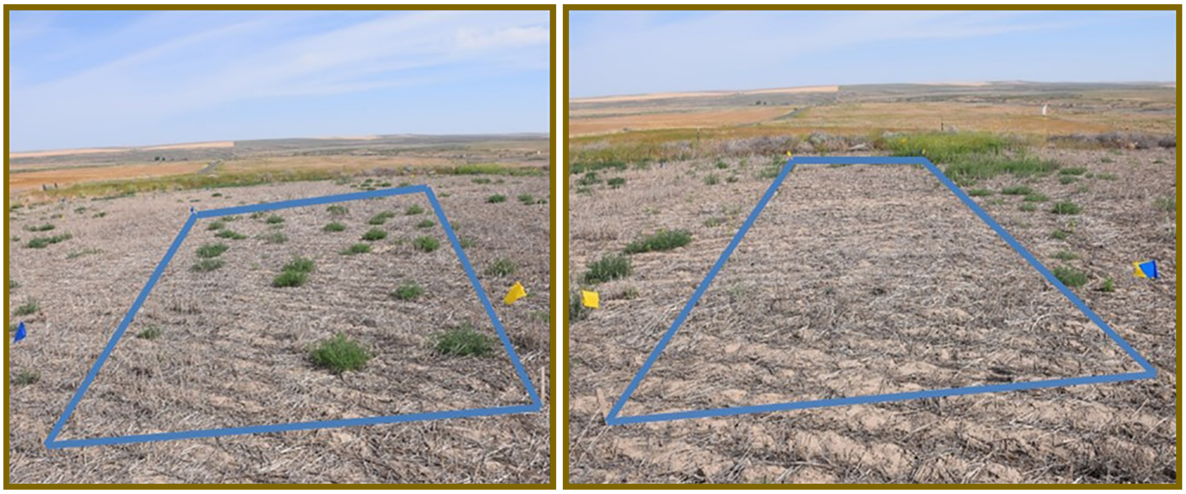


Figure 1. Individual plot photos were taken on July 9, 2019 to document Russian-thistle distribution within the trial area. The photo on the left was a nontreated check plot. The photo on the right was a plot treated with Spartan Charge (8 fl oz/A) on November 28, 2018, the late fall application timing.

Russian-thistle was the only broadleaf weed that was uniformly dispersed throughout the trial area for the duration of the trial. We were able to take one rating (May 15th) on the activity of these treatments for control of tumble mustard. Although Spartan Charge applied in the late fall provided significantly better control of tumble mustard than the nontreated check (Table 1), it was not as good as Spartan Charge applied in the late winter or the split application, both of which provided control comparable to the remaining treatments evaluated. On the initial May 15th rating date, all treatments were providing excellent control of Russian-thistle, except TriCor applied in the late fall. Spartan Charge treatments, regardless of application timing, were the only treatments providing significantly better control of Russian-thistle than the nontreated check plots on the June and July rating dates. The results of this trial suggest that preemergence herbicides can provide an alternative means of controlling Russian-thistle in chemical fallow and may become necessary as glyphosate-resistant Russian-thistle becomes more prevalent.

Table 1. Tumble mustard and Russian-thistle plant counts in response to late fall and late winter preemergence herbicide applications in chemical fallow near Lind, WA.

Treatment	Rate	Application Timing[1]	Tumble mustard plants per square yard	Russian-thistle plants per square yard		
	(oz/A)		5/15/19	5/15/19	6/13/19	7/9/19
Nontreated check	--	--	12.3 c[2]	14.6 c	0.2 b	0.4 cd
Spartan Charge	8 fl oz	LF	2.8 b	0.0 a	0.0 a	0.0 a
Spartan Charge	8 fl oz	LW	0.1 a	0.0 a	0.0 a	0.0 a
Spartan Charge	4 fl oz fb 4 fl oz	LF fb LW	0.1 a	0.0 a	0.0 a	0.0 a
Fierce	4.5	LF	0.0 a	0.2 a	0.2 b	0.5 cd
Fierce	4.5	LW	0.0 a	0.4 a	0.2 b	0.3 c
Fierce	2.25 fb 2.25	LF fb LW	0.0 a	0.0 a	0.1 ab	0.3 c
TriCor	10.5	LF	0.0 a	4.9 b	0.2 b	0.7 d
TriCor	10.5	LW	0.0 a	0.2 a	0.1 ab	0.3 c
TriCor	5.25 fb 5.25	LF fb LW	0.1 a	0.4 a	0.2 b	0.4 cd

[1] Application timing: Late fall (LF) and Late winter (LW)

[2] Means, based on four replicates, within a column, followed by the same letter are not significantly different at P = 0.05 as determined by Fisher's protected LSD test, which means that we are not confident that the difference is the result of treatment rather than experimental error or random variation associated with the experiment.

How Russian Thistle Germination Changes with Soil Water Potential

NICHOLAS G. GENNA[1] AND STEWART B. WUEST[2]
[1]COLUMBIA BASIN AGRICULTURAL RESEARCH CENTER, OSU; [2]USDA-ARS, SOIL AND WATER CONSERVATION RESEARCH UNIT

Russian thistle is a persistent summer annual weed in dryland farming regions of eastern Oregon and Washington. Russian thistle can cause significant crop loss in spring crops or during drought due to its C4 photosynthetic pathway and high water use efficiency. Since this weed grows well in low soil moisture, we were interested in how germination changed with soil moisture. We were also interested in comparing germination across Russian thistle populations.

We chose Russian thistle seed from four locations in Oregon including the cities of Adams, Moro, Pendleton, and a farmer's field in Umatilla County. We prepared nine Walla Walla silt loam soil treatments by adjusting soil water potential from a low of -3.0 to a high of -0.64 MPa or 7.0-10% water content on a dry mass basis, respectively. We sealed seeds inside Petri dishes with each soil, placed the dishes in a constant 25.0 oC growth chamber, and monitored germination for 10 days.

Germination percent and rate increased with soil moisture and was largely complete by day six (Fig. 1A). Germination was similar across populations and not observed below -1.6 MPa (8.2% water content) in any population. Final germination percent was > 83% when averaged across populations in soils wetter than -0.73 MPa (10% water content) (Fig. 1B).

This preliminary trial demonstrated that the minimum soil water potential that Russian thistle may germinate lies between -1.6 and -2.3 MPa; similar to published studies on wheat. This is good news for farmers, since Russian thistle may not possess a germination advantage over wheat or other spring crops in drier soils. These results also add to the current theory that the best Russian thistle control strategy centers on reducing emergence and establishment in crop.

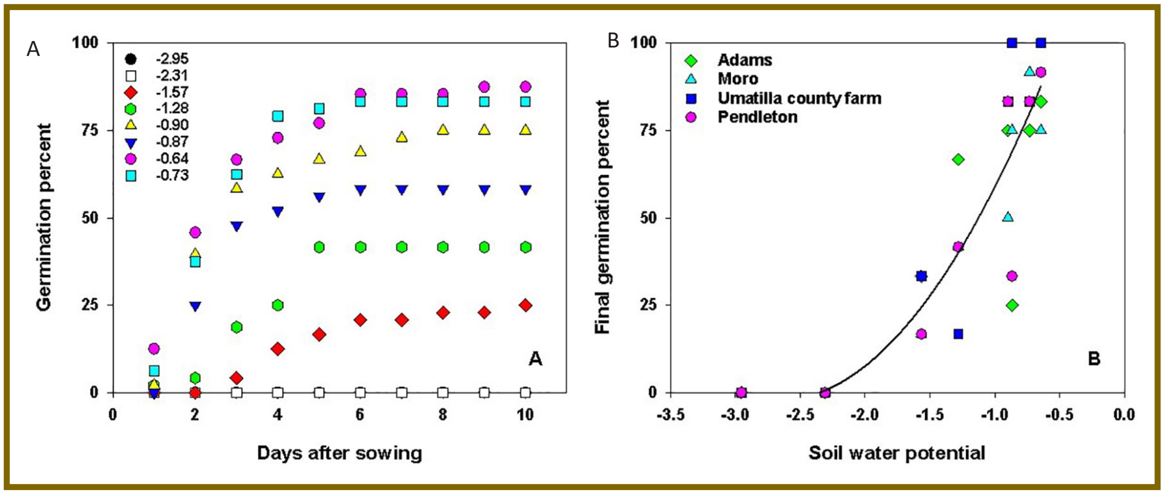


Figure 1. Germination of Russian thistle seeds collected from four populations in Oregon. A) Cumulative germination averaged across populations for each water potential treatment and B) the change in final germination percent with soil water potential.

Eyespot, Cephalosporium Stripe, and Snow Mold Diseases of Winter Wheat

TIM MURRAY, HONGYAN SHENG, AND SAMODYA JAYASINGHE
DEPT. OF PLANT PATHOLOGY, WSU

Eyespot and Cephalosporium stripe are common diseases of winter wheat across all of the wheat-producing area of eastern Washing, but especially in the higher-rainfall regions. They have potential to cause loss in grain yield up to 50% for eyespot and 80% or more for Cephalosporium stripe. In contrast, snow mold diseases historically have been a problem on about 200,000 acres in the north-central wheat-producing area of WA near the Waterville Plateau, and can cause complete yield loss when a susceptible variety is grown, and disease is severe.

Planting a resistant variety is the best control for these diseases. Our research has focused on identifying new and effective resistance genes to these three diseases and testing new varieties for resistance. Over the past 15 years, we have tested new varieties and advanced breeding lines for eyespot and Cephalosporium stripe resistance in inoculated field trials and used that information to provide variety ratings available on the WSU Extension Small Grains Team website (http://smallgrains.wsu.edu) and the Washington State Crop Improvement Seed Buyer's Guide. Several varieties are available with effective resistance or tolerance to all three of these diseases. We recommend consulting the results of the WSU Variety Testing plots near you and selecting the most resistant variety that does well in your area.

In addition to resistant varieties, several foliar fungicides are registered for eyespot control. We have two field trials evaluating the effectiveness of seven foliar fungicide treatments and six seed treatment fungicides in limiting the damage caused by eyespot. We will report the results of these trials following harvest in August on the Small Grains Team website and at meetings this fall and winter. The same seed treatments were tested for their effect on snow mold in Douglas County at two locations, one of which resulted in small differences among treatments.

Soil acidification is a widely occurring problem in the inland Pacific Northwest. Mahler documented the decrease in soil pH in north Idaho and eastern Washington from 1960 to 1980 and showed that over 65% of the agricultural soils in the region had pH less than 6.0 by 1980. In 1992, we confirmed that Cephalosporium stripe increased in acidic soils and showed that it could be controlled by adding lime to raise pH > 6.0. However, 25 years later liming is still not practiced on a large scale and soil acidification has continued to the point where aluminum toxicity has become a problem in some areas. We have begun studies looking at the impact of biochar and paper mill fly ash application on soil pH, incidence/severity of Cephalosporium stripe, and productivity in pot studies and small plot trials at two locations. Biochar and fly ash are alternatives to conventional agricultural lime. Fly ash is a by-product of paper production that has high lime value and is currently sent to the landfill; if effective, it may be a less expensive alternative to lime. Biochar and fly ash, along with agricultural lime were applied alone and in combination to raise soil pH from below 5.0 to 5.7, which Mahler identified as the threshold for yield loss. Four varieties ranging in susceptibility to Cephalosporium and aluminum were then planted. Soil pH increased and free aluminum decreased in the top 3" of the soil profile where fly ash and agricultural lime were applied, but there was no change with biochar application. We will evaluate disease and yield responses this summer and are planning to repeat the experiment in 2020-2021.

Oviposition and Larval Development of the Hessian Fly *Mayetiola destructor* (Diptera: Cecidmyiidae) on Different Host Plants

ROHOLLAH SADEGHI, STEVEN ODUBIYI, ATOOSA NIKOUKAR, AND ARASH RASHED
DEPT. OF ENTOMOLOGY, PLANT PATHOLOGY AND NEMATOLOGY, UI

The Hessian fly, *Mayetiola destructor*, is a major pest of spring wheat in the Pacific Northwest region of the USA. After oviposition by the mated females, the larvae move to the base of the leaves and establish feeding sites and gall. This process not only leads to significant damage to the host plants, but also substantial yield loss. Planting resistant wheat cultivars is the most effective control method against this pest. Although Hessian flies can damage barley, anecdotal evidence from experimental wheat plots, planted within a barley field, suggested that barley may be resistant to this pest. To better understand Hessian fly response to different host types, we designed a series of experiments to assess host choice and oviposition of the mated females, as well as the larval survivorship, on susceptible (Alturas) and resistant (Hollis) wheat varieties, as well as barley (Champion) and oat (Cayuse). In our host choice trials, females laid more eggs on either wheat varieties compared to oat or barley hosts (Fig. 1). Surface light reflectance showed that leaves of both susceptible and resistant wheat varieties had same interactions with light, and differed from barley and oat, this might be an important physical cue for the mated females to choose their host for oviposition. Our no-choice assays however indicated that the Hessian fly larvae are unable to develop into their pupal stage and consequently adults on the resistant wheat and oat hosts. No significant difference in larval survivorship was detected between the susceptible wheat (Alturas) and the barley (Champion), while adult emergence was significantly higher for the barley as a host compared to the susceptible wheat (Fig. 2). Phytohormonal evaluation was revealed that endogenous salicylic acid (SA) may contribute in activating the plant defense systems against the Hessian fly larvae with higher concentrations in oat and resistant wheat variety. Susceptible and resistant wheat varieties are suitable hosts for oviposition by the Hessian fly, but the larvae development just occurs on the susceptible wheat. Hessian flies do not prefer barley as a host for oviposition compared to the wheat, although barley is a suitable host for larvae to survive and emerge as adults. Oat on the hand, is not a preferred host for oviposition, and the larvae do not survive on it.

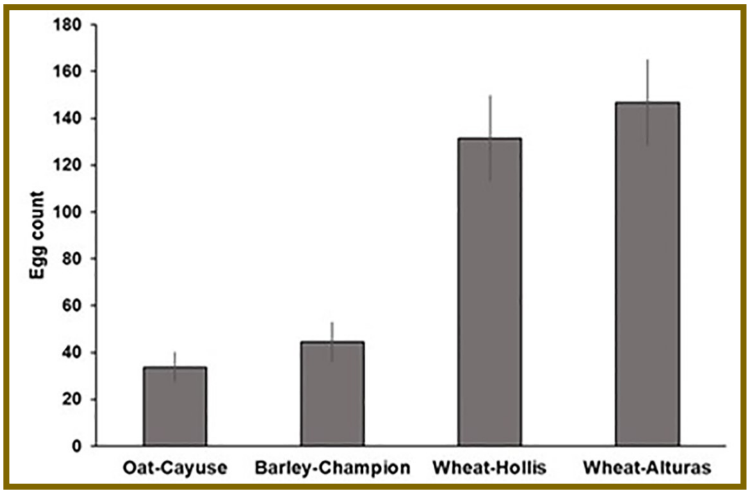


Figure 1. Oviposition (number of eggs per plant) by the Hessian fly female in a choice test.

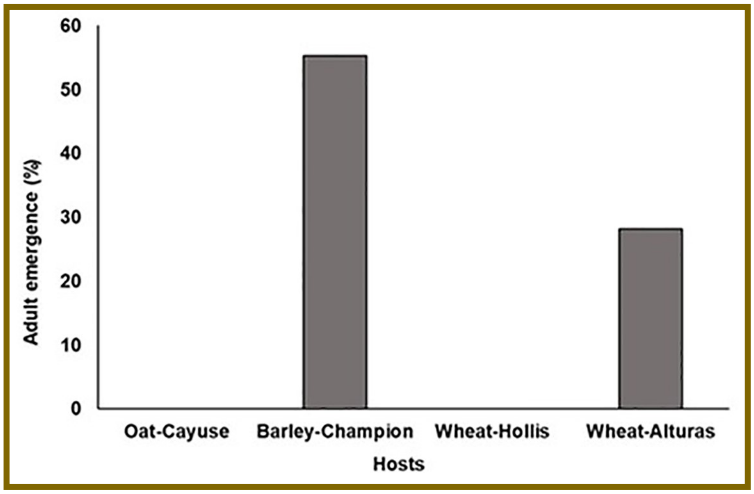


Figure 2. Percentage of adult emergence on each host plant in no choice test.

Part 3. Breeding, Genetic Improvement, and Variety Evaluation

OSU Cereal Extension Program Updates

RYAN C. GRAEBNER, DAISY RUDOMETKIN, AND MATTHEW HUNT
COLUMBIA BASIN AGRICULTURAL CENTER, OSU

The Oregon Cereal Extension Program provides growers with performance information on commonly grown and newly released wheat and barley varieties from public and private breeding programs. Wheat varieties are evaluated in four trials (the Oregon Soft Winter Elite Yield Trial or OWEYT; the Hard Winter Elite Yield Trial or HWEYT; the Oregon Soft Spring Elite Yield Trial or OSSYT; and the Oregon Hard Spring Elite Yield Trials or OHSYT) while barley varieties are evaluated in two trials (the Oregon Spring Barley Variety Trial or OSBVT and the Oregon Winter Barley Variety Trial or OWBVT). This year, we are conducting trials in 21 locations throughout Oregon, eastern Washington, and northern California. Trial data is released as soon as possible after harvest via our website, https://agsci.oregonstate.edu/wheat/osu-wheat-variety-trials, so that this information may be used to make planting decisions for the following crop year. Key traits we evaluate include yield, test weight, grain protein, plant height, and heading date. In addition, we collaborate with Professor Chris Mundt, Professor Andrew Ross, and the Western Wheat Quality Laboratory to evaluate the entries for disease resistance and end-use quality. Program priorities include ensuring that our testing conditions reflect production conditions, maintaining consistency in the locations we test from year to year, and testing experimental lines as early as possible to build an understanding of their performance before they are released.

Due to COVID-19 concerns this year, we will release a short video focusing on key recent variety releases when field days would normally happen, followed by in-depth looks at variety performance as soon as we have data from the harvested crops. In addition, we hope to have varieties labeled at several on-farm locations around the state, so that people can view the varieties in person.

Washington State University Extension Cereal Variety Testing Program

CLARK NEELY[1], BRANDON GERRISH[2], AND ANDREW HORTON[2]
[1]WSU EXTENSION; [2]DEPT. OF CROP AND SOIL SCIENCES, WSU

The WSU Extension Cereal Variety Testing Program conducts variety trials at 27 physical locations throughout eastern Washington. In total, the program conducts 24 soft white winter, 17 hard winter, 18 soft white spring, and 18 hard spring wheat trials in addition to 12 spring barley trials. Four sites are co-managed with WSU and USDA breeders while our Eureka and Walla Walla sites are cooperative sites between WSU and OSU Extension. The Variety Testing Program also works in concert with multiple research programs within WSU, U of I, and USDA to further screen varieties for traits such as end use quality, falling number susceptibility, acid soil tolerance, insect resistance, and disease resistance.

The primary goal of the program is to produce comprehensive, reliable, and unbiased data for growers, agribusiness industry, university researchers and other clientele to use and make informed decisions. The use of sound statistical methodology and uniform testing procedures allow for the comparison of varieties both within and across environments. Trials are grouped together into four precipitation zones, plus irrigated sites, and span from the Highway 2 corridor in the north to the Walla Walla Valley in the south in order to capture the diverse climates found in the state.

Preliminary data is sent out via email list serve immediately following harvest and then posted online on the small grains website (http://smallgrains.wsu.edu). Printed copies of the data can also be found in the final comprehensive Cereal Variety Testing

Annual Report and Wheat Life Magazine articles. Typically, results are discussed and distributed at grower meetings and field days throughout the year, however in-person field days have been cancelled for 2020. "Virtual" field days will be recorded at select locations and posted on the College of Agriculture, Human, and Natural Resources YouTube Channel (https://www.youtube.com/user/WSUCAHNRS/).

Clientele can also utilize the "Variety Selection Tool" at https://varietyselection.cahnrs.wsu.edu/. Once the class of wheat and precipitation zone have been selected, this interactive tool allows users to sort and select varieties based on multiple traits and thresholds in order to find a variety that meets their needs. Data provided on the tool includes two- and three-year yield averages, test weight, grain protein, multiple disease ratings, end use quality, falling number rating, and much more. Growers are also welcome to walk the plots at any time. Plot maps are posted on our website with directions to the sites.

Winter Wheat Breeding and Genetics at WSU

A. CARTER, K. BALOW, A. BURKE, K. HAGEMEYER, G. SHELTON, A. STOWE, AND J. WORAPONG
DEPT. OF CROP AND SOIL SCIENCES, WSU

The Winter Wheat Breeding and Genetics Program at Washington State University remains committed to developing high yielding, disease resistant, and high end-use quality cultivars for release to maintain sustainability of production. We use tools such as genomic selection and high-throughput phenotyping to accomplish this task and are excited about the breeding lines under evaluation and their release potential. We have a strong doubled haploid production system which generates about 3,000 lines annually. About 200 populations each year are selected with molecular markers for important genes for disease resistance and end-use quality. Genomic selection efforts, which use the entire genome instead of one or two markers, have recently included models for traits such as snow mold, stripe rust, and emergence. Collaboratively with the Spring Wheat and USDA Wheat breeding programs, and groups in Biological Systems Engineering and Statistical Genomics, we are expanding our systems of high-throughput phenotyping, looking for ways we can use data collected for indirect predictions of breeding line performance. In collaboration with the Weed Science program we are expanding our efforts to develop herbicide tolerance in winter wheat to benefit the growers of the state, as well as finding ways to make the wheat plant more competitive with weeds. Selection under field conditions continues for emergence from deep planting, basic agronomic characteristics, diseases such as stripe rust, snow mold, eyespot foot rot, Cephalosporium, stripe, SBWMV, Fusarium crown rot, and nematodes, tolerance to low pH soils and cold temperatures, end-use quality, and many more too numerous to list! The Winter Wheat Program continues to work effectively and efficiently to develop winter wheat cultivars with high yield potential and required agronomics, disease resistance, and end-use quality parameters for the state of Washington.

Releases from the WSU winter wheat program include **Otto**, **Puma**, **Jasper**, **Purl, Sequoia, Earl,** and **Sprinter**. We also participated in the collaborative release of **Curiosity CL+**, **Mela CL+**, **Resilience CL+**, **ARS-Pritchett,** and **ARS-Castella**. Lines released are well adapted for production in Washington and the Pacific Northwest, are high yielding, have good test weight, good cold tolerance, and have a combination of tolerance/resistance to stripe rust, eyespot foot rot, snow mold, nematodes, and low pH soils as needed. Recent released include the following:

Stingray CL+ which is a two-gene imazamox resistant line broadly adapted to both Washington and Oregon. It has topped almost every yield trial it has been in when compared to other two-gene lines. It has good stripe rust resistance, eyespot resistance, and cold tolerance.

Devote is a soft white winter wheat with excellent yield potential in the less than 12-inch rainfall zones. It has high test weight, excellent tolerance to snow mold and cold temperatures, stripe rust resistance, eyespot resistance, and Fusarium crown rot resistance.

Scorpio is a hard red winter wheat targeted to the intermediate and high rainfall areas targeted to replace Keldin. It has high yield potential, stiff straw that withstands lodging, stripe rust resistance, cold tolerance, and very good end-use quality attributes.

A couple lines to keep an eye on this summer are **WA8305 CL+** and **WA8306 CL+**. Both lines performed very well in 2019 trials and are on seed increase pending release approval. Additional lines to watch are **WA8293**, **WA8290**, and **WA8308**, which have high yield potential and excellent disease resistance, and are being looked at for release potential.

Two Soft White Winter Wheat Cultivars -- VI Bulldog and VI Frost

YUEGUANG WANG[1] AND JAY KALOUS[2]
[1]DEPT. OF PLANT SCIENCES, UI; [2]LIMAGRAIN CEREAL SEEDS

The University of Idaho has continued its joint soft white winter wheat development in partnership with Limagrain Cereal Seeds. The goal of this effort is to continue developing superior soft white winter wheat cultivars to serve growers in the Pacific Northwest. In 2019, the first jointly developed cultivars were released under the label Varsity Idaho (VI).

VI Bulldog, common soft white winter wheat (Triticum aestivum L.), was co-released by UI and LCS in 2019. VI Bulldog was derived from the cross of ‘92-16004A//02F D-194/Bitterroot’. It has apically awnletted heads. Its plants are blue-green at boot stage. VI Bulldog was selected for high yield potential, excellent resistance to stripe rust and Fusarium crown rot (FCR), extremely strong straw and excellent end-use quality. VI Bulldog is targeted to high production acreage in the 16-20+ rainfall zones or under irrigation.

VI Frost, common soft white winter wheat (*Triticum aestivum* L.), was co-released by UI and LCS in 2019. VI Frost was a Brundage 96 derivative because it was derived from the back cross of ‘R04-200/Brundage 96//Brundage 96’. It has awned heads. Its plants are green at boot stage. VI Frost has excellent winter-hardiness, good snow mold tolerance, good stripe rust tolerance and excellent end-use quality. VI Frost is targeted to the intermediate to low rainfall zones that receive less than 16 inches of rainfall annually or are prone to moderate levels of snow mold in eastern Washington along Highway 2 from Spokane to Almira.

Developing an Immunoassay for Late Maturity α-amylase (LMA) and Preharvest Sprouting (PHS)

AMBER L. HAUVERMALE[1], ANDY MCCUBBIN[2], MICHAEL O. PUMPHREY[1], AND CAMILLE M. STEBER[1,3]
[1]DEPT. OF CROP AND SOIL SCIENCES, WSU; [2]SCHOOL OF BIOLOGICAL SCIENCES, WSU; [3]USDA-ARS WHEAT HEALTH, QUALITY, AND GENETICS UNIT, WSU

There are two genetic factors that lead to high α-amylase enzyme expression outside of a normal germination program in wheat. These are late maturity α-amylase (LMA), occurring during grain filling in response to a cold shock, and preharvest sprouting (PHS) occurring after seed maturation in response to a rain event. The Hagberg-Perten Falling numbers test (FN) measures starch damage caused by α-amylase and other enzymes in the flour and is the industry standard for measuring flour quality. While LMA and PHS contribute to a low FN, they do so through different molecular mechanisms, and the effect on end-use quality may not be equivalent. The Falling Numbers test cannot directly determine differences in LMA and PHS physiology or the impacts to end use quality. To address the limitations in the existing technology an immunoassay platform using monoclonal antibodies to wheat α-amylases and other germination specific enzymes is being developed as a more reliable test for LMA and PHS.

Wheat α-amylases 1 and 2 (TaAMY1/2) are highly induced during LMA and PHS and were the primary targets for α-amylase antibody development. A total of 6 monoclonal peptide antibodies were raised against known peptide sequences to TaAMY1/2. Of these, three (TaAMYa, TaAMYb, and TaAMYc) were further purified and tested for their ability to detect TaAMY proteins induced in aleurones treated with gibberellin (GA) as a proxy for LMA or PHS. Western blot analysis confirmed that all three TaAMY antibodies detected the presence of a 44 kDa band in GA treated fractions, consistent with the expected size for TaAMY proteins. TaAMYc antibody showed the strongest avidity (Fig. 1). Amino acid sequencing from a Coomassie stained SDS-PAGE gel slice containing the 44 kDa band confirmed sequence homology to both TaAMY1 and TaAMY2.

Successful immunoassay development not only requires antibody specificity but that antibodies are able to function in pairs; one for target protein capture and one for target protein detection. Previous research reported that colloidal gold-conjugated detection antibodies are sensitive enough to detect α-amylase from wheat seeds in a quantitative fashion. To further validate the use of TaAMY antibodies in a Lateral Flow Immunoassay (LFI) and to test detection sensitivity using colloidal gold, an immunoprecipitation pipeline was developed. TaAMYa, TaAMYb, and TaAMYc were linked to Protein A magnetic beads and used to capture α-amylase targets from GA induced aleurone fractions. Colloidal gold-conjugated TaAMYc was used for detection. Western blot analysis confirmed that all three TaAMY antibodies were all suitable for α-amylase protein capture, and gold-liked TaAMYc was capable of detection (Fig. 2). Based on these results TaAMYa and TaAMYc will be used together for ongoing LFI and 96 -well high-throughput ELISA platform construction. A parallel pipeline is also being developed for the germination specific enzyme 1,3 β-glucanase.

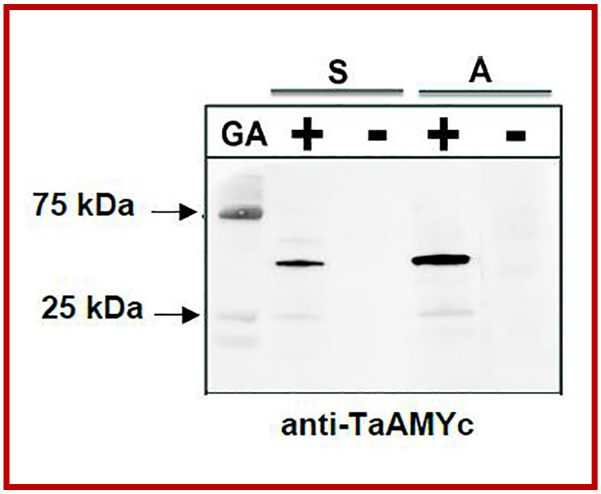


Figure 1. **The expression of the wheat α-amylase proteins in aleurone is induced by the germination-stimulating hormone GA and detected with anti-TaAMY1c monoclonal antibody. Aleurone tissues isolated from wheat cultivar Chinese Spring were incubated with shaking for 3 days at room temperature in 10 mM $CaCl_2$ buffer with or without 10 μM GA_3. A total of 20 μg of total protein from either the secreted (S) fraction, or ground aleurone (A) tissues was loaded per lane and detected with TaAMYc (1:500).**

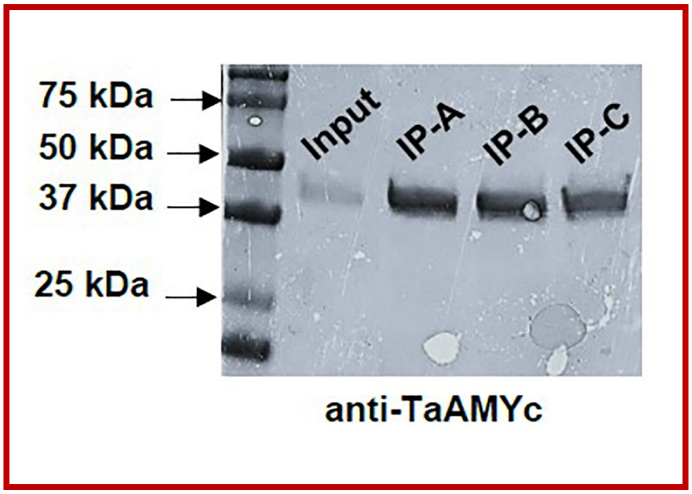


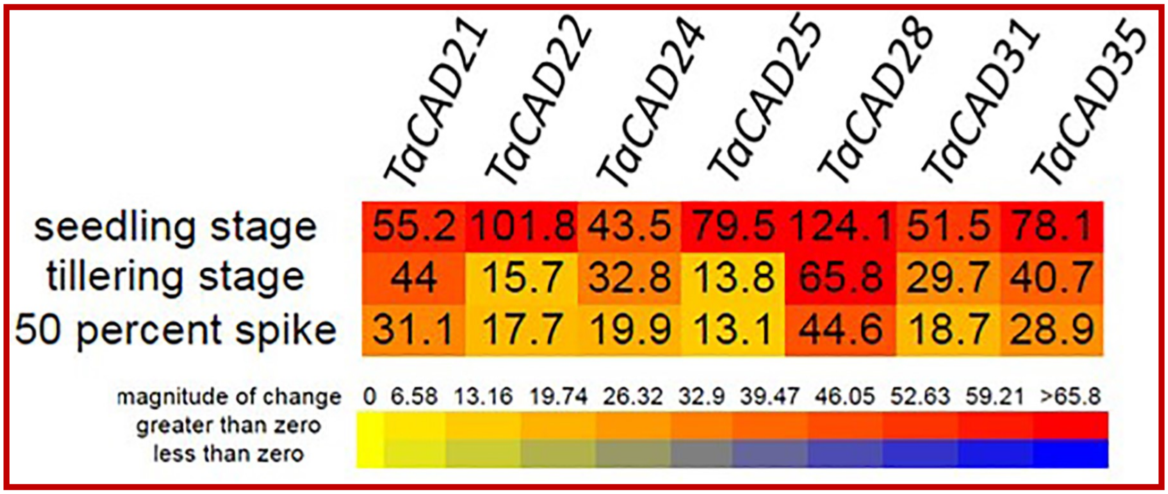
Figure 2. **TaAMY1a, TaAMY1b, and TaAMY1c antibodies were combined with Protein A magnetic beads (1:8v/v) and used to capture α-amylase protein from secreted aleurone fractions treated with 10 μM GA_3. A total of 40 μg of protein was loaded per lane and detected with gold labeled TaAMY1c (1:500). A single band of approximately 44 kDa was detected in each lane indicating that all three antibodies detected native protein, and that TaAMY1c is not altered when conjugated with colloidal gold for detection.**

Exploring *CAD* Genes as Agents for Stress-Tolerant Wheat

LUIGI M. PERACCHI, RHODA A.T. BREW-APPIAH, AND KAREN A. SANGUINET
DEPT. OF CROP AND SOIL SCIENCES, WSU

Unpredictable weather patterns threaten to offset previously reliable wheat yield estimations. This has the dual effect of decreasing food availability and more importantly reducing the economic prospects of farmers in the Pacific Northwest. This downward trajectory can be rectified by exploring two major genetic pathways in wheat: stress tolerance/resistance mechanisms and root development pathways critical for water and nutrient uptake. In previous literature, researchers made a connection between the deposition of lignin, a complex plant polymer which provides mechanical strength, and stress tolerance. They studied the wheat lignin biosynthesis gene family *cinnamyl alcohol dehydrogenase* (*TaCAD*) in this context (DOI: 10.1093/jxb/erq107), but the limitations regarding resolution of the wheat genome led to an incomplete identification of specific gene family members that could be important for organ-specific expression and for responses to biotic and abiotic stress.

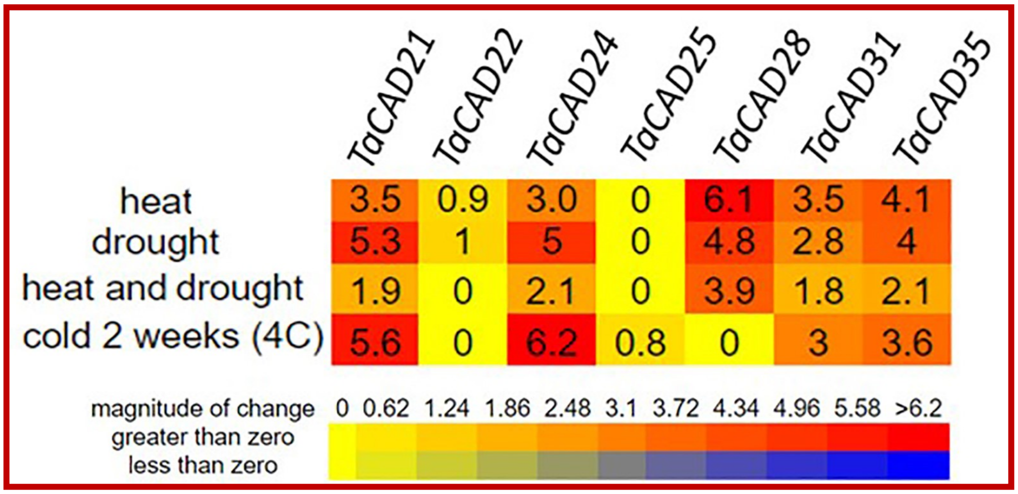
Using the newly released bread wheat genome, we found 35 extra additional unique *TaCAD* genes in addition to the 12 known wheat *CADs* discovered in previous studies. Seven of these *TaCADs* including one that had been previously identified (*TaCAD31*), have an active role in seedling root development and establishment which is critical for yield (Fig. 1). We looked at the expression of these seven genes to heat and drought which are common stressors in dryland wheat farming in the Pacific Northwest. Generally, these genes are active during both development and stress (Fig. 1, Fig. 2). In addition, some genes that had been highly active during development were downregulated during heat and drought stress (Figure 2). Four of these genes were moderately active at low temperatures and all seven were active during fungal attack (Fig. 2).



	TaCAD21	*TaCAD22*	*TaCAD24*	*TaCAD25*	*TaCAD28*	*TaCAD31*	*TaCAD35*
seedling stage	55.2	101.8	43.5	79.5	124.1	51.5	78.1
tillering stage	44	15.7	32.8	13.8	65.8	29.7	40.7
50 percent spike	31.1	17.7	19.9	13.1	44.6	18.7	28.9

Figure 1. Root-specific expression of the seven *TaCADs* with significant detectable levels during the seedling stage, tillering stage, and 50 percent spike stage. The values represent the amount of gene transcript present in the sample at the time of testing. The red color indicates greater amount of relative transcript.

There is potential in the exploration of root systems for the development of wheat varieties with enhanced architecture for better water/nutrient uptake and stress tolerance. By increasing heat, drought and cold stress tolerance in roots through *TaCAD* activity during the crucial seedling establishment and grain filling stages, stress-related yield loss can be mitigated. Moreover, the size of farming operations in the Pacific Northwest makes identification of diseases early on difficult. By increasing the stress-induced activity of *TaCAD* in roots, it has the possibility to increase resistance to soil-borne pathogen attack, meaning less field maintenance and higher gross grain yield. In addition, because TaCAD functions in the latter stages of the lignin biosynthetic pathway and downstream of potential master regulators controlling multiple pathways, unintended consequences from breeding these genes into other wheat cultivars are expected to be minimal.



	TaCAD21	*TaCAD22*	*TaCAD24*	*TaCAD25*	*TaCAD28*	*TaCAD31*	*TaCAD35*
heat	3.5	0.9	3.0	0	6.1	3.5	4.1
drought	5.3	1	5	0	4.8	2.8	4
heat and drought	1.9	0	2.1	0	3.9	1.8	2.1
cold 2 weeks (4C)	5.6	0	6.2	0.8	0	3	3.6

Figure 2. Expression levels of the seven TaCADs of interest during fungal pathogen attack, heat, drought and cold stress. The values represent the amount of gene transcript present in the sample at the time of testing. The red color indicates greater amount of relative transcript.

Charactering the Genetics of LMA in North American Spring Wheat

CHANG CHLOE LIU[1], REHANA S. PARVEEN[1], SAMUEL R. REVOLINSKI[1], KIMBERLY A. GARLAND CAMPBELL[1,2], MICHAEL O. PUMPHREY[1*], AND CAMILLE M. STEBER[1,2*]
[1]DEPT. OF CROP AND SOIL SCIENCE, WSU; [2]USDA-ARS, WHEAT HEALTH, GENETICS AND QUALITY UNIT,
*THE LAST TWO AUTHORS CONTRIBUTED EQUALLY TO THIS WORK.

This study examined whether genetic susceptibility to late maturity alpha-amylase (LMA) is a possible cause of low falling numbers in N. American spring wheat grain. LMA has been described as the accumulation of the enzyme alpha-amylase in wheat grain in response to either a cold temperature swing or continuous cool temperatures when the grain is in the soft dough stage of development, also known as the late maturation stage (Zadock 85). LMA has been well characterized in Australian wheat and is a major breeding objective in Australia because higher falling numbers are needed to compete well in the international wheat market.

Alpha-amylase produced during germination is a good thing because it digests the starchy endosperm as fuel for seedling growth. Normally, alpha-amylase expression should decrease as the grain matures. Elevated alpha-amylase in mature grain is considered a bad thing because starch digestion reduces its gelling capacity leading to higher risk of poor end-product quality and causes low falling numbers (FN). Farmers receive a discount for grain with a falling number below 300 seconds because overseas customers will not risk purchasing grain with an FN below 300. It appears that northwest wheat has problems with low FN due to LMA because we have had episodes where low FN was not associated with rain after the wheat matured and because we have been able to detect the pattern of alpha-amylase expression expected in LMA-affected grain. This study examined two questions: 1) How widespread is LMA susceptibility in North American wheat? and 2) Can we map genes/QTLs that will help us to select against LMA using molecular markers?

To address this, we characterized LMA susceptibility in a panel of 256 hard spring wheat lines, representing ten North American wheat breeding programs. Approximately 79% of the lines showed moderate to severe LMA susceptibility following cold-induction experiments. The highest LMA resistance was in Minnesota and Manitoba and the lowest in CIMMYT wheat. It should be possible to improve LMA resistance in Washington and Idaho wheat to be more like that found in Minnesota. Although LMA showed a high degree of variability between three independent experiments (estimated heritability of 0.4), we were able to perform a preliminary genome-wide association study. Six significant marker-trait associations were detected on chromosomes 1A, 3A, 3B, 6B, 7B, and 7D. The QLMA.wsu.7B and QLMA.wsu.6B loci detected in this study co-localized within 16 cM and 1 cM of QTL previously detected in Australian and CIMMYT

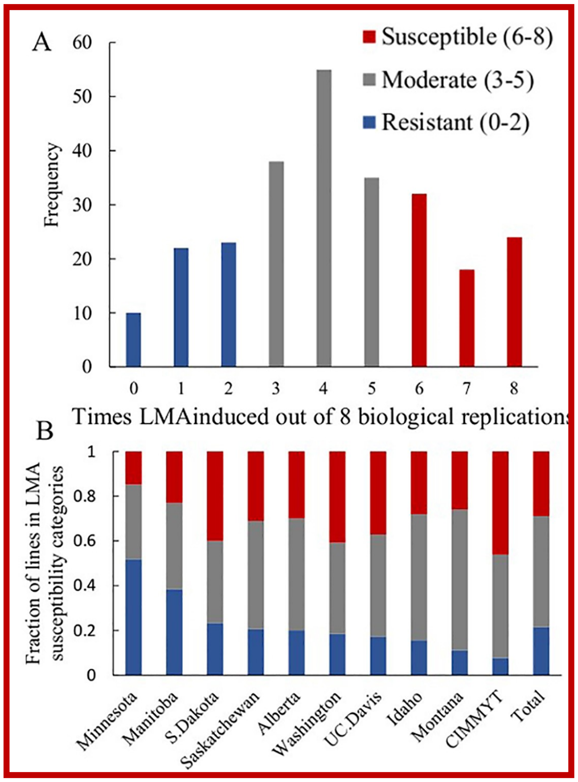


Figure 1. The distribution of LMA phenotypes in the panel of 256 North American breeding lines. A) The frequency of each phenotypic category in the AM panel based on the number of times that LMA was induced over the combined 8 replications from 3 experiments. B) Fraction of LMA phenotypic categories by breeding program. Categories of LMA susceptibility were defined based on the number of biological replicates showing LMA induction (A620 > 0.2) out of the combined 8 replications in the two greenhouse and one field experiment. Bars show the fraction of susceptible (74), moderate (127), and resistant (55) lines.

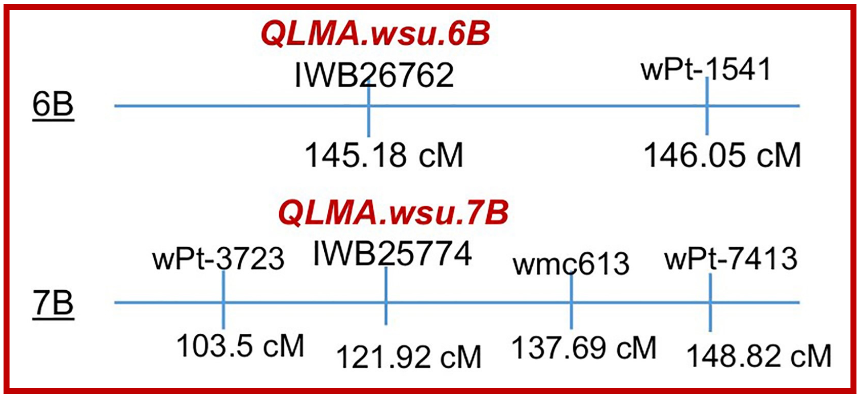


Figure 2. Map position of QTL from this study (red) relative to previously published QTL (black) wPt-1541, wPt-3723, wmc613, and wPt-7413.

germplasm, respectively. Thus, the causes of genetic susceptibility may be similar. Future work will better define the QTL detected in two-parent mapping populations and examine if selection for these QTL can increase FN and LMA resistance in breeding lines.

Table 1. Putative significant QTL for LMA.

[1]GH QTL	Marker	Chr	Position	$-\log_{10}(p)$	[2]Effect	MAF	[3]**Fav** allele	n
QLMA.wsu.3B	IWB63008	3B	801300	8.6	0.09	0.10	**A**/G	242
QLMA.wsu.1A	IWB35476	1A	1512200	6.4	-0.05	0.33	T/**C**	120
QLMA.wsu.6B	IWB26762	6B	1104500	7.0	-0.07	0.11	T/**C**	120
Field QTL								
QLMA.wsu.3A	IWB11852	3A	207400	6.9	0.16	0.26	A/C	206
QLMA.wsu.7B	IWB25774	7B	1335900	9.8	0.16	0.25	A/G	206
QLMA.wsu.7D	IWB48862	7D	861900	9.9	0.17	0.24	T/C	206

[1] GH = greenhouse

[2] The positive Effect values indicate elevated risk of LMA phenotype in N. America hard red spring wheat TCAP association panel

[3] The major allele that reduce the susceptibility of LMA in N. America hard red spring wheat TCAP association panel

Picture This: Using A Bird's-Eye View to Improve Genetic Gain in a Wheat Breeding Program

ANDREW HERR AND ARRON CARTER
DEPT. OF CROP AND SOIL SCIENCES, WSU

Multispectral imaging with unmanned aerial vehicles is a promising high-throughput phenotyping technology that has shown to help understand the mechanisms associated with crop productivity. Figure 1 illustrates how with multispectral imaging, we can evaluate the relationship between plant health and plant reflectance values. This established relationship allows us to accurately predict complex agronomic traits like grain yield within a given generation by precisely identifying the health of the plant through the use of indices. Multispectral imaging creates the potential for accelerated variety selection in a breeding program.

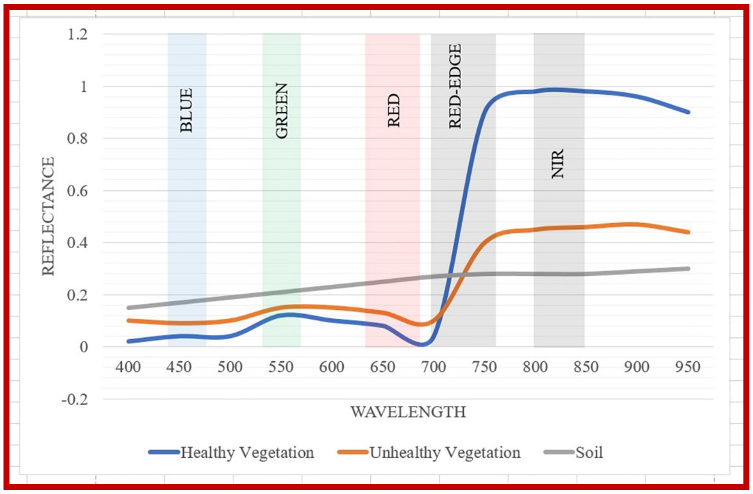


Figure 1. Influence of plant vegetation health on reflectance at different wavelengths. Highlighted wavelength bands blue, green, red, red-edge, and NIR are wavelength bands sampled during data collection.

Unfortunately, multispectral imaging has not been validated as a suitable breeding tool for predicting crop performance across years. The WSU winter wheat breeding program has set out to determine the effectiveness and efficiency in prediction across years and locations within the existing breeding pipeline. Breeding lines have been evaluated with this new phenotyping method across the state of Washington since 2018, with plans to continue evaluations through 2022. Data is being collected at heading with a DJI Inspire 1 drone, equipped with a Sentera quad-camera obtaining eight multispectral bands. Reflectance data collected at heading has shown, in previous research, to have the highest correlation with important agronomic traits in soft white wheat. Lines are observed from single location, single replication preliminary yield trials to multi-location, replicated advanced yield trials. Lines advanced in the breeding program will be evaluated across 20 different location-year trials. New lines that are added to the breeding program each year will also be assessed to further enhance the number of lines being tested.

Our preliminary results validate that predictions within a single generation have a high correlation to grain yield within a trail year, indicating that plant health at heading has a direct influence on grain yield. Figure 2 shows the variation and detail that can be obtained with the collection of multispectral reflectance images. When we account for environmental variation, the correlation between reflectance and grain yield increases in both low and high rainfall regions, indicating a strong genetic relationship.

Moving forward, the data collected from these trials will be used in indirect selection to estimate how well they predict the performance of breeding lines across multiple location-years. Additionally, reflectance values will be used as fixed effects in mixed models and genomic prediction modeling to estimate their usefulness in genomic selection further. This research will be vital for plant breeders to understand the value of multispectral imaging to improve winter wheat varieties while using fewer resources.

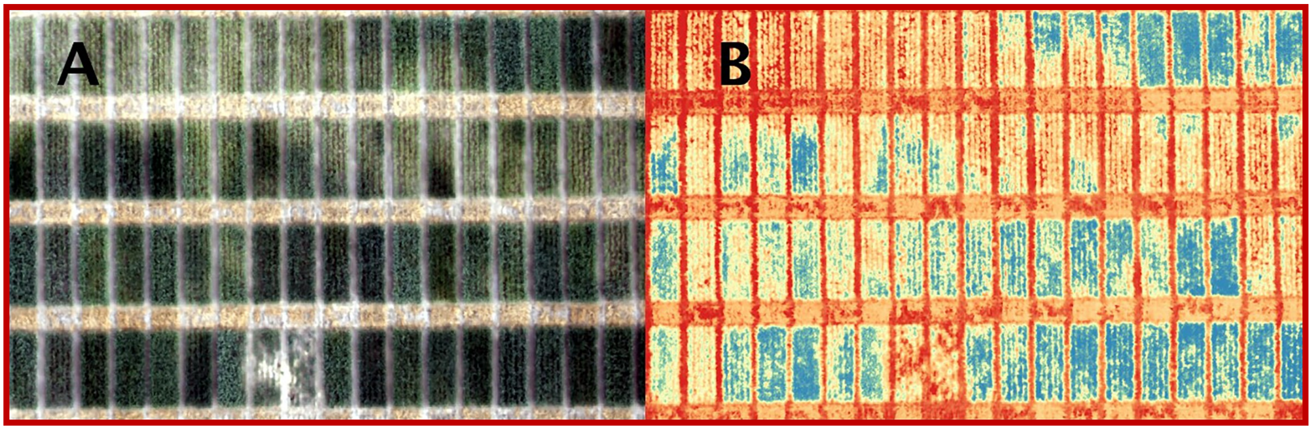


Figure 2. Image A shows a traditional RGB image of a highly variable portion of the Davenport winter wheat test plots. Image B is a color scale of reflectance values of the same plot, showing a much clearer image of environmental variation and crop performance.

Analysis of *SALP1* Genes in Wheat for Stress Tolerance

RHODA A.T. BREW-APPIAH AND KAREN A. SANGUINET
DEPT. OF CROP AND SOIL SCIENCES, WSU

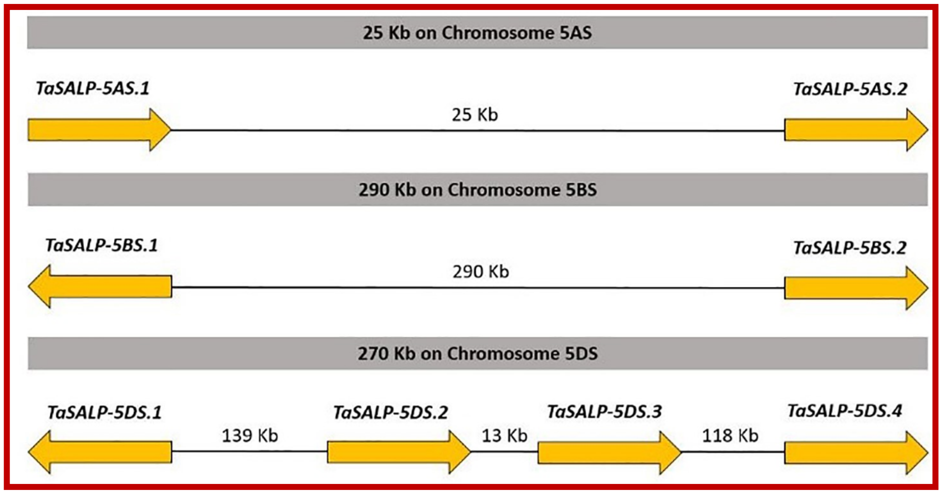
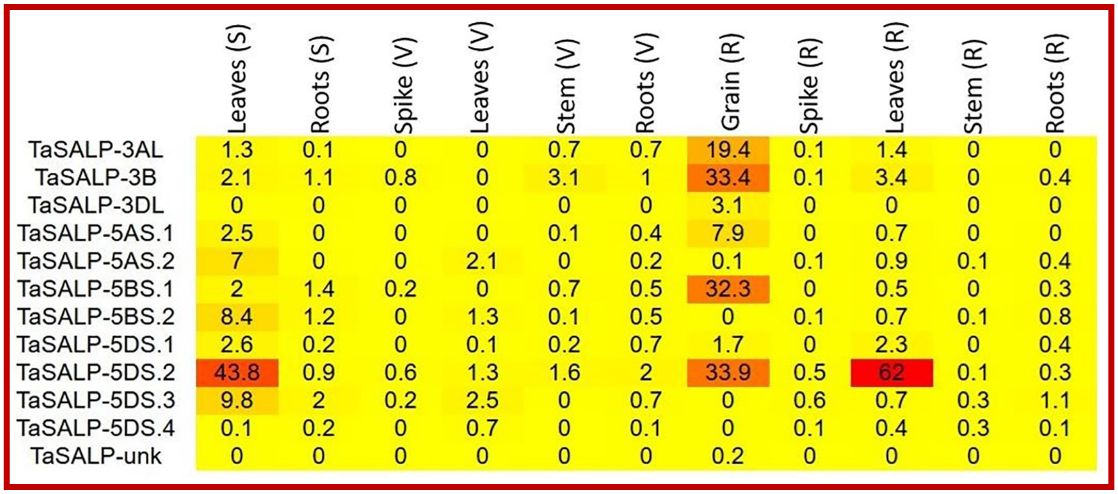


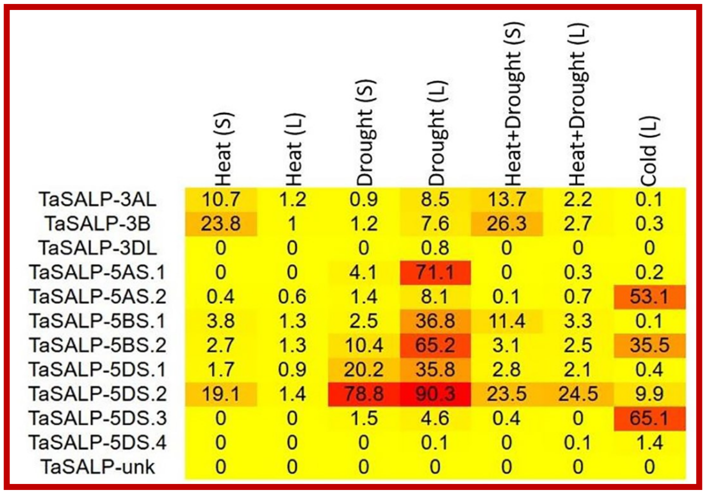
Figure 1. Distribution of select wheat *SALP* genes on the respective chromosomes. Diagram not to scale.

It is estimated that by 2050, there will be a 20% drop in precipitation rates in the dryland wheat-growing areas of Washington state and the subsequent drought conditions could cause a decline in yield and baking quality. Previously, we showed that there were seven copies of a drought-responsive gene called *SALP1* (*Stress Associated Little Protein 1*) in bread wheat (*TaSALP*) (**Dryland Field Day Abstract, 2018**). Leveraging the newly released and higher resolution wheat reference genome we found an additional five *TaSALP* genes bringing the total number to 12 copies. These 12 copies are predominantly located on the long arms of chromosome 3 and the short arms of chromosome 5 in bread wheat (Fig. 1). We discovered that some of the genes on chromosome 5 had moderate to high levels of expression during the seedling stage (*TaSALP-5DS.2, TaSALP-5DS.3, TaSALP-5BS.2, TaSALP-5AS.2*) (Fig. 2). During the reproductive and grain filling stage, genes on both chromosome 3 and chromosome 5 were activated (*TaSALP-3AL*, *TaSALP-3B*, *TaSALP-5AS.1*, *TaSALP-5BS.1*, *TaSALP-5DS.2*) (Fig. 2). In summary, the most active developmental phase for wheat *SALP* genes is at grain fill (Fig. 2).



	Leaves (S)	Roots (S)	Spike (V)	Leaves (V)	Stem (V)	Roots (V)	Grain (R)	Spike (R)	Leaves (R)	Stem (R)	Roots (R)
TaSALP-3AL	1.3	0.1	0	0	0.7	0.7	19.4	0.1	1.4	0	0
TaSALP-3B	2.1	1.1	0.8	0	3.1	1	33.4	0.1	3.4	0	0.4
TaSALP-3DL	0	0	0	0	0	0	3.1	0	0	0	0
TaSALP-5AS.1	2.5	0	0	0	0.1	0.4	7.9	0	0.7	0	0
TaSALP-5AS.2	7	0	0	2.1	0	0.2	0.1	0.1	0.9	0.1	0.4
TaSALP-5BS.1	2	1.4	0.2	0	0.7	0.5	32.3	0	0.5	0	0.3
TaSALP-5BS.2	8.4	1.2	0	1.3	0.1	0.5	0	0.1	0.7	0.1	0.8
TaSALP-5DS.1	2.6	0.2	0	0.1	0.2	0.7	1.7	0	2.3	0	0.4
TaSALP-5DS.2	43.8	0.9	0.6	1.3	1.6	2	33.9	0.5	62	0.1	0.3
TaSALP-5DS.3	9.8	2	0.2	2.5	0	0.7	0	0.6	0.7	0.3	1.1
TaSALP-5DS.4	0.1	0.2	0	0.7	0	0.1	0	0.1	0.4	0.3	0.1
TaSALP-unk	0	0	0	0	0	0	0.2	0	0	0	0

Figure 2. Global expression analysis of the wheat *SALP* gene family at various developmental stages (Seedling (S), Vegetative (V), Reproductive (R)). The expression values are in transcript per million bases (TPM). The progression from yellow to red indicates low to high expression levels.



	Heat (S)	Heat (L)	Drought (S)	Drought (L)	Heat+Drought (S)	Heat+Drought (L)	Cold (L)
TaSALP-3AL	10.7	1.2	0.9	8.5	13.7	2.2	0.1
TaSALP-3B	23.8	1	1.2	7.6	26.3	2.7	0.3
TaSALP-3DL	0	0	0	0.8	0	0	0
TaSALP-5AS.1	0	0	4.1	71.1	0	0.3	0.2
TaSALP-5AS.2	0.4	0.6	1.4	8.1	0.1	0.7	53.1
TaSALP-5BS.1	3.8	1.3	2.5	36.8	11.4	3.3	0.1
TaSALP-5BS.2	2.7	1.3	10.4	65.2	3.1	2.5	35.5
TaSALP-5DS.1	1.7	0.9	20.2	35.8	2.8	2.1	0.4
TaSALP-5DS.2	19.1	1.4	78.8	90.3	23.5	24.5	9.9
TaSALP-5DS.3	0	0	1.5	4.6	0.4	0	65.1
TaSALP-5DS.4	0	0	0	0.1	0	0.1	1.4
TaSALP-unk	0	0	0	0	0	0	0

Figure 3. Global expression analysis of the wheat *SALP* gene family under various environmental stresses (short term (S), long term (L). The expression values are in transcript per million bases (TPM). The progression from yellow to red indicates low to high expression. *In order to increase the resolution of the heat map, the value for *TaSALP-5DS.2* under Drought (L) has been decreased by a factor of 10.

Expression of the *TaSALP* gene family is also triggered during stress. Members of the *TaSALP* family that are dormant or have low levels at the seedling or vegetative phases have increased levels during heat, drought or combined heat and drought stresses (*TaSALP-3AL, TaSALP-3B, TaSALP-5AS.1, TaSALP-5BS.1, TaSALP-5DS.1*) (Fig. 2, Fig. 3). Others that are active during these developmental phases maintain or increase their expression levels during heat and/or drought stress (*TaSALP-5BS.2, TaSALP-5AS.2, TaSALP-5DS.2*) (Fig. 2, Fig. 3). The *SALP* gene originally discovered in rice (DOI:10.1007/s11105-015-0944-0) was responsive to heat, drought and salt but not to cold. This is not surprising as the former three stresses tend to coexist in the environment. However, during normal wheat development, cold snaps can lead to suboptimal yields. An investigation of genes known to be involved in low temperature stress would therefore be useful in determining which genes or loci would be crucial in future breeding efforts for cold tolerance. We found four wheat *SALP* genes with moderate to high levels at low temperatures (*TaSALP-5AS.2, TaSALP-5BS.2, TaSALP-5DS.2* and *TaSALP-5DS.3*) (Fig. 3). This is distinct from rice where there was only one gene that was generally unresponsive to cold.

Prior to our initiation of investigations into this gene involved in stress tolerance in rice, there was no information on wheat *SALP* genes. We have shown that this gene exists as multiple copies in wheat and is responsive to heat, drought and cold stress. Our observations increase our understanding of plant-environment interactions and subfunctionalization of gene families in wheat but more crucially, provide specific loci that can be incorporated into breeding programs to develop more stress tolerant wheat and maintain optimal yields.

Genomic Selection of Stripe Rust Resistance in a Wheat Breeding Program

Lance F. Merrick[1], Arron H. Carter[1], Xianming Chen[2], and Brian P. Ward[3]
[1]Dept. of Crop and Soil Sciences, WSU; [2]USDA-ARS Wheat Health, Genetics and Quality Research Unit and Dept. of Plant Pathology, WSU; [3]USDA-ARS Plant Science Research Unit, Raleigh, NC

Stripe rust is one of the most damaging diseases of wheat and has resulted in massive reduction in yield and economic losses globally. Stripe rust can cause more than 90% yield losses in fields planted with susceptible cultivars. The use of resistant varieties and fungicide applications are the primary methods to control stripe rust. Quantitative adult plant resistance (APR) is detected in adult plants, associated with resistance usually to all stripe rust races, and considered to be a durable form of resistance. Plant response to stripe rust is measured by infection type (IT) and disease severity (SEV). IT is the measurement of stripe rust infection on a scale of 0 to 9, and SEV is the percentage of leaf area showing disease symptoms. APR is controlled by varying numbers of resistance genes and thus is a good candidate for genomic selection. Genomic selection allows us to create a statistical model to predict a trait using genetic data. Genomic selection models are built upon the trait data of previous years and allows prediction of future breeding lines using genetic data and in the absence of current year trait data. The goal of this research was to create a genomic selection model to identify breeding lines with APR in our winter wheat breeding program.

In order to create a genomic selection model, we used many breeding lines with both phenotypic data for APR and genetic data. These groups of breeding lines are called training populations. We used a training population consisting of breeding lines from three years (2016-2018) composed of 2,629 unique breeding lines. The models used genetic data called genotype-by-sequencing single-nucleotide polymorphism markers, which allow us to collect a large number of genetic markers to account for all of the genes that control APR. We also used DNA markers for the *Yr17* resistance gene, which is the most common disease resistance gene in our germplasm and allows us to account for this resistance in our statistical model.

Our preliminary results showed that the prediction model with the highest accuracy was a genomic best linear unbiased prediction model that uses genetic relatedness between breeding lines. Figure 1 shows the results for our genomic selection model using different experimental designs to obtain the best phenotypic data in our trials. The model reached an accuracy of 0.58 for infection type and 0.54 for disease severity based on lines in a single year. The accuracy of our model is a measure of the genomic selection model to predict the phenotypic observation of a breeding line and ranges from 0 to 1, with 1 being a perfect prediction. The results show that by using a row-column design, we can better control the differences in our environment to produce a more accurate genomic selection model. Genomic selection will aid the breeding program in the identification and selection of stripe rust resistance. This allows us to still make selections and progress based on the genetic information of the lines, even when we do not have the actual disease present to make those selections. The breeding lines selected will have a more durable stripe rust resistance that will have a better ability to exhibit resistance even with new races of the stripe rust pathogen from year to year.

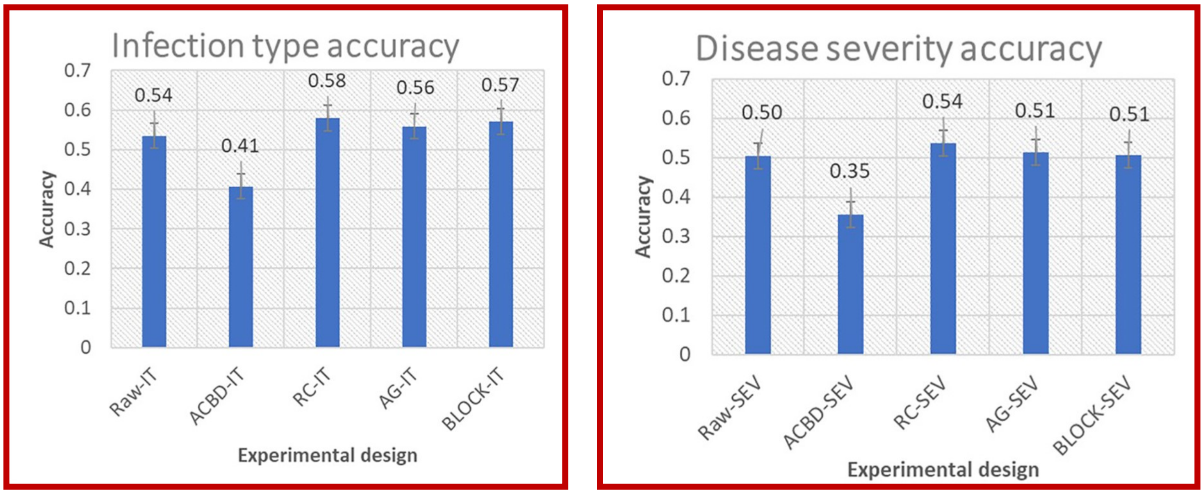


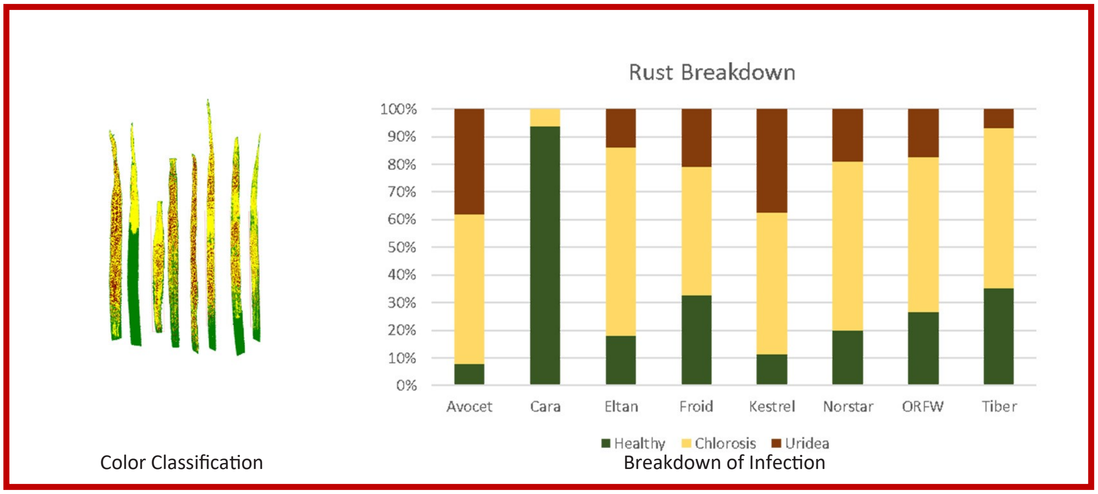
Figure 1. Prediction accuracy of genomic selection models for infection type (left) and disease severity (right) using different experimental designs in order to obtain the best phenotypic data in our trials. The different experimental designs consist of the raw data, augmented complete block designs using various software, and a row-column design with the row-column design providing the highest prediction accuracy.

Developing a Phenomics Program for Plant Biology Utilizing Two Automated Phenomics Platforms

Brian S Bellinger[1], Kim Garland-Campbell[1], Patricia Okubara[2], and Evan Stowe[3]
[1]U.S. Dept. of Agriculture – Dept. of Crop and Soil Sciences, WSU; [2]U.S. Dept. of Agriculture – Dept. of Plant Pathology, WSU; [3]Dept. of Horticulture, WSU

In an effort to improve screening procedures for wheat and other crop breeding programs at Washington State University, USDA-ARS has invested in two Phenomics platforms to evaluate plants exposed to biotic and abiotic stresses. The LemnaTec Phenocenter utilizes a high throughput plant-to-sensor system where plants are loaded onto trolleys and automatically transferred to a Phenocenter where RGB and 3D images are taken. LemnaTec provided software has been used to analyze the images in a way to produce a desired data set that may be further analyzed statistically. Additionally, the Phenospex Drought spotter and PlantEye system was purchased to evaluate plants under automatic watering while taking 3D images over a period of time. Algorithms developed by Phenospex have been used to calculate digital biomass and plant growth. These systems have been used to evaluate a diverse set of plant species and traits. We are using these systems to evaluate rate of root growth, rust resistance, aluminum resistance, seed contamination, rate of spread of bacteria, and drought tolerance.

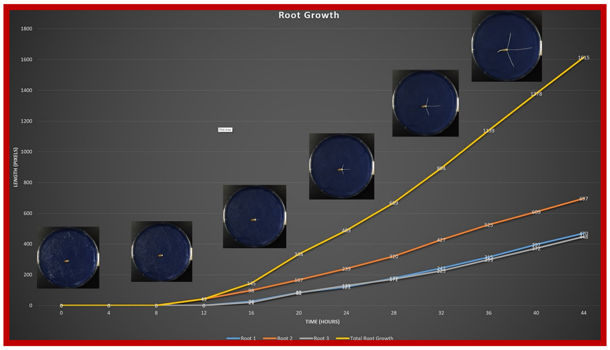
Acknowledgment: This project was supported by USDA CRIS Project No. 2090-21000-033-00D.



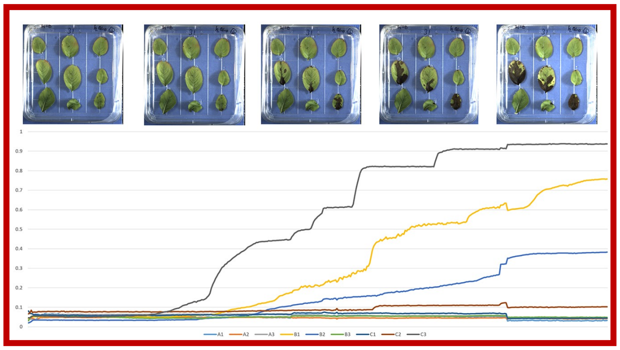
Color Classification

Breakdown of Infection

Project: Leaf Rust Screening for Wheat Seedlings
Principle Investigator: Kim Garland Campbell



Project: Rate of Wheat Root Growth
Principle Investigator: Patricia Okubara



Project: Fire Blight in Pear leaves
Primary Investigator: Evan Stowe

Integrating Spectral Information and Genomic Selection for Predicting Grain Protein Content in Wheat

KARANSHER SANDHU[1], PAUL MIHALYOV[2], MEGAN LEWIEN[3], MICHAEL PUMPHREY[1], AND ARRON CARTER[1]
[1]DEPT. OF CROP AND SOIL SCIENCES, WSU; [2]DEWEY SCIENTIFIC; [3]U.S. FOREST SERVICE

Grain protein content (GPC) is an important end-use quality determinant for hard red spring wheat (*Triticum aestivum* L.). Improvement and prediction of GPC have been a major concern of wheat breeders due to its negative correlation with grain yield. Selections for GPC are performed after the harvest of promising lines in the field. High-throughput phenotyping methods have the potential for significantly improving the predictions for GPC. Genomic selection models can integrate the spectral information and possibly aid in making selections earlier in breeding cycles. We applied genomic selection models by combining genotype and spectral reflectance information for predicting the GPC in untested wheat lines.

A nested association mapping population of 650 lines was planted between 2014 and 2016 at Spillman Agronomy Farm in Pullman, WA. GPC was measured from these lines using a Perten DA 7000 NIR analyzer. Spectral information was collected during the heading and grain filling stage and used to calculate vegetation indices (e.g., normalized difference vegetation index or NDVI, simple ratio or SR, etc.). This population was genotyped using genotyping-by-sequencing and 90K Illumina SNP chip assay. Genomic selection models were trained using marker information and vegetation indices for predicting the GPC, with 80% of the data used for training and 20% used for prediction accuracy of the model, repeated 50 times.

Eight different vegetation indices were calculated using spectral reflectance information. Genomic selection accuracy was obtained for all three years separately either using marker information or including indices in the model. We observed that indices collected at the heading stage were superior for predicting GPC compared to grain filling stage. Overall, including vegetation indices in the selection models results in improving prediction accuracies for GPC (Fig. 1). Green normalized difference vegetation index (GNDVI) was most effective at improving the prediction for GPC. This could be due to its high correlation with GPC or it measures reflection for senescence of wheat, which acts as an indirect measure for GPC. This study demonstrated the ability of predicting GPC using genotype and vegetation indices with a relatively high accuracy.

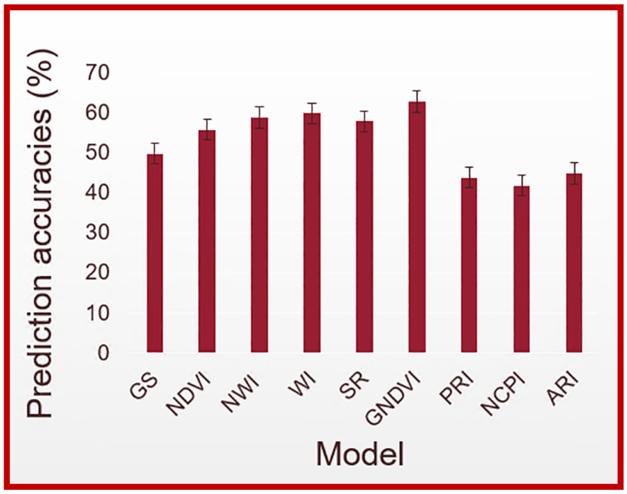


Figure 1. Comparison of genomic selection (GS) accuracies including eight different vegetation indices, for prediction of grain protein content in hard red spring wheat.

The USDA-ARS Western Wheat Quality Laboratory

CRAIG F. MORRIS, ALECIA M. KISZONAS, AND DOUGLAS A. ENGLE
USDA-ARS WESTERN WHEAT QUALITY LABORATORY

The mission of the USDA-ARS Western Wheat Quality Lab is two-fold: conduct milling, baking, and end-use quality evaluations on wheat breeding lines, and conduct research on wheat grain quality and utilization. Our web site: http://wwql.wsu.edu/ provides great access to our research and publications.

Our current research projects include soft durum wheat, grain hardness, 'Super Soft' wheat, arabinoxylans, puroindolines, polyphenol oxidase (PPO), and waxy wheat. Our recent publications include mapping kernel texture in soft durum wheat, published in the Journal of Cereal Science. The identification of a *ph1b*-mediated 5Ds-5BS crossing over site in soft-kernel durum wheat lines was published in Euphytica. The agronomic traits in durum wheat germplasm possessing puroindoline genes were studied and published in Agronomy Journal. A study on the physical mapping of peroxidase genes and development of functional markers for *TaPod-D1* on bread wheat chromosome 7D was published in Frontiers in Plant Science on-line journal. Identification of loci and molecular markers associated with Super Soft kernel texture in wheat was published in the Journal of Cereal Science. The genetic analysis of a unique 'super spft' kernel texture phenotype in soft white spring wheat was published in the Journal of Food Science. A review on the antimicrobial properties of puroindolines was published in the World Journal of Microbiology and Biotechnology. A note on a device for the detection of wheat seeds with waxy endosperm was published in Cereal Chemistry. Research on the genome-wide association of feruloyl arabinoxylan content in common wheat grain was published in the Journal of Cereal Science. Recent wheat varieties that have been developed in collaboration with WSU, OSU and USDA-ARS scientists include Curiosity CL+, Mela CL+, Resilience CL+, Purl, and USDA Lori.

Low Falling Number Problems May Result from Vivipary, the Germination of Immature Wheat Grain

SARAH R. PEERY[1] (S.PEERY@WSU.EDU), REHANA S. PARVEEN[1], TRACY HARRIS[2], MATTHEW WYSOCK[1], MICHAEL O. PUMPHREY[1], AND CAMILLE M. STEBER[1,2] (CAMILLE.STEBER@USDA.GOV)
[1]DEPT. OF CROP AND SOIL SCIENCES, WSU; [2]USDA-ARS, WHEAT HEALTH, GENETICS AND QUALITY UNIT

This study examined if immature grain could germinate, possibly causing problems with low falling numbers. The Hagberg-Perten Falling Number (FN) method measures the presence of the starch-digesting enzyme alpha-amylase in wheat grain, such that a lower FN indicates elevated alpha-amylase enzyme activity in the grain. Grain with an FN below 300 seconds is discounted because overseas buyers have found that such grain has a higher risk of giving poor end-product quality, such as cakes that fall, sticky noodles, or bread that sticks to the blade when sliced. The Steber lab is identifying genetic loci associated with higher resistance to late maturity alpha-amylase (LMA) and preharvest sprouting in order to help breeders select varieties with less risk of low FN. Preharvest sprouting is the initiation of germination on the mother plant by rainfall after maturity, while LMA is the induction of alpha-amylase by cool temperature during the soft dough stage of grain filling (around 24 to 30 days past anthesis or pollen shedding). LMA is induced by moving plants or cut spikes into a cold chamber with a 64°F day and a 45°F night. If the LMA cold chamber was too humid, the grain germinated on the mother plant. This was surprising because textbooks tell us that seeds don't germinate until after they reach physiological maturity. This suggests that some of the problems with low FN might result from a genetic tendency for VIVIPARY, the germination of grain during rainfall BEFORE the wheat reaches maturity. We are curious if this is a 3rd cause of low FN, or if it is genetically related to LMA or preharvest sprouting.

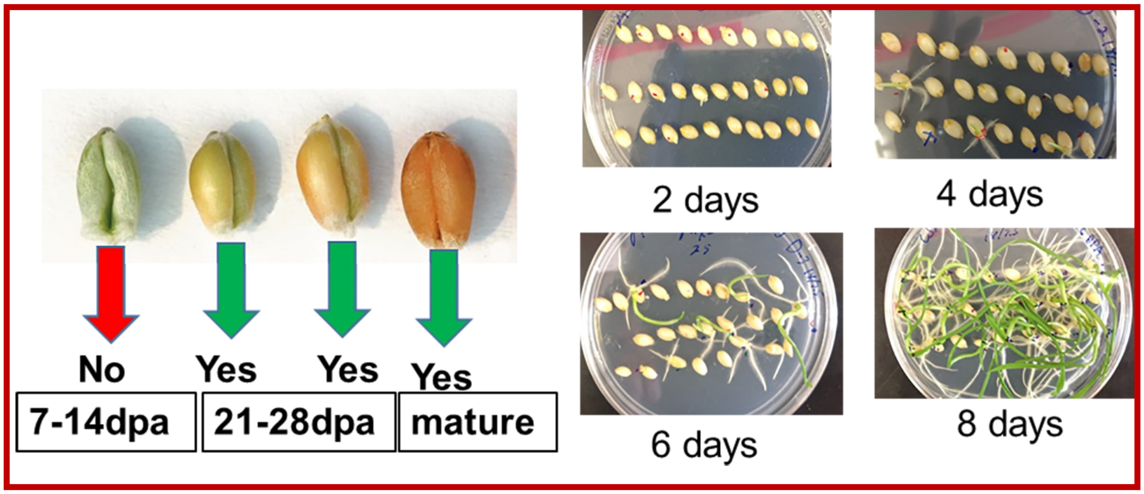


Figure 1. Vivipary/germination of wheat grain before maturity. Soft white spring WA8124 was unable to germinate at 7-14 days past anthesis (dpa), but able to germinate during the soft to hard dough stage 21-28 dpa. Grain were dissected from spikes of wheat at the indicated number of days after anthesis/pollen shedding. They were kept moist until placed on nutrient agar, then incubated under a 16 hr day, with an 18°C/64°F daytime and 7.5°C/45°F night time temperature. Germination was examined daily. Photos show germinate of grain at 24 dpa.

To test if wheat can germinate during grain filling, grains were removed from spikes of soft white spring WA8124 at specific time points after anthesis (Fig. 1). Grain was unable to germinate while still green at 7 and 14 days past anthesis (dpa), but began to show germination as it lost green coloration at 21 to 28 dpa in the soft dough and hard dough stages. Immature grain germinated slower than mature grain. Next, we examined if vivipary was associated with LMA susceptibility. We looked at 3 previously characterized cultivars, LMA resistant ‘Halberd’, LMA-susceptible ‘Kennedy’, and ‘Seri-82’ a cultivar where LMA is always on even without cold treatment. Halberd is resistant to vivipary/premature germination, while Kennedy and Seri-82 are susceptible (Fig. 2). There was more germination when immature grain was incubated at lower than a higher temperature. We were able to recreate this vivipary phenotype by misting spikes on live plants, suggesting that this can happen in a farmer’s field (Fig. 3). Thus, it appears that some wheat cultivars can undergo vivipary or germination well before physiological maturity. Future work will need to examine if vivipary is associated with LMA susceptibility in a larger number of cultivars. We are also interested in examining if vivipary is associated with increased alpha-amylase expression, leading to low FN.

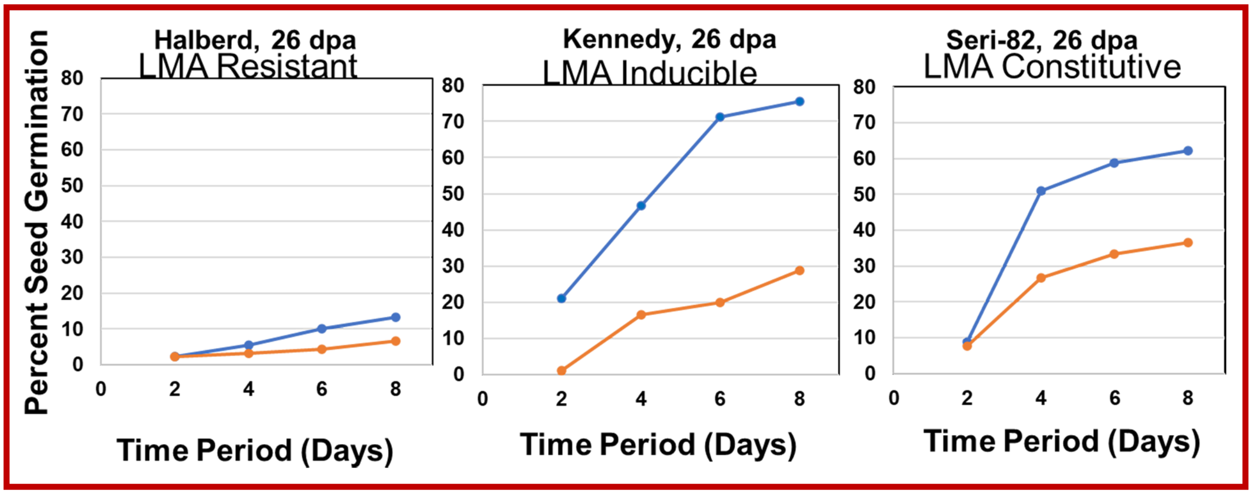


Figure 2. Cold promoted vivipary, germination before physiological maturity. Grain were collected from spikes at 26 dpa and placed on nutrient agar as described in Figure 1. Grain were incubated at either a warm (red line, 25°C/77°F day time and 18C/64F night time) or cold (blue, 18C/64F daytime and 7.5°C/45°F night time) temperature. The LMA resistant line Halberd was less prone to vivipary than the two LMA susceptible lines, Kennedy and Seri-82.

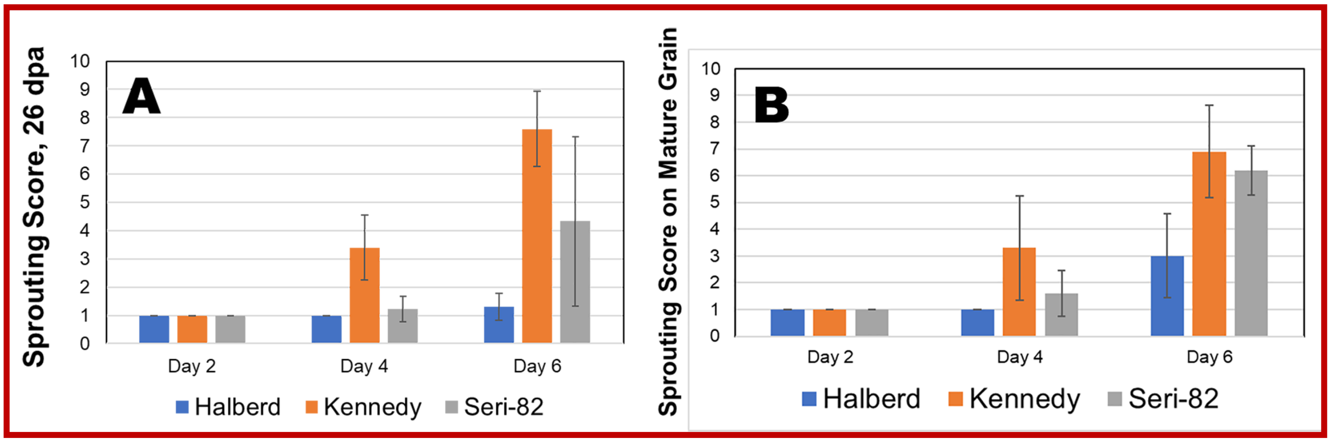


Figure 3. Spike-wetting tests during the soft dough stage of grain development. Whole plants were moved to a cool (18°C/64°F daytime and 7.5°C/45°F night time) misting chamber when the spikes on the plants were between 21 and 26 dpa. The appearance of visible sprouting was scored based on a 1 to 10 scale where a higher number indicates more advanced stages of sprouting. Sprouting scores at the soft dough stage (A., 26 dpa) are compared to those obtained with plants after physiological maturity (B).

Mapping of Genes/Loci Controlling Preharvest Sprouting and Emergence in Northwest Wheat

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JASON WIGEN[1*], STEPHANIE SJOBERG[1*], KIMBERLY GARLAND CAMPBELL[1,2*], ARRON H. CARTER[1*], AND CAMILLE M. STEBER[1,2*]
[1]DEPT. OF CROP AND SOIL SCIENCES, WSU; [2]USDA-ARS, WHEAT HEALTH, GENETICS AND QUALITY UNIT
*ALL AUTHORS CONTRIBUTED EQUALLY TO THIS WORK.

This study is developing molecular markers as a tool to breed for preharvest sprouting tolerance combined with good seedling emergence in winter wheat. Preharvest sprouting is the initiation of germination on the mother plant when rainy conditions occur before harvest. Sprouting causes problems with poor end-product quality because it results in the production of the enzyme alpha-amylase in the grain. Alpha-amylase digests starches into sugars, a good thing if you want to fuel seedling growth but a bad thing if you want to produce high quality baked goods. Alpha-amylase can be produced before the grain is visibly germinated. As a result, farmers can get a bad surprise when they go to sell the mildly sprouted grain and the presence of alpha-amylase is detected in the form of a low Falling Number (FN). Grain and flour with too much α-amylase activity has poor gelling capacity, resulting in a low FN and in quality problems such as cakes that fall and sticky bread and noodles. The risk is high enough that overseas buyers will not accept grain with an FN below 300 seconds. We can reduce risk of low FN by breeding wheat with higher preharvest sprouting tolerance. The problem is that higher preharvest sprouting tolerance is associated with higher grain dormancy, which in turn may result in slow or poor seedling emergence, especially under low moisture and deep-planting conditions.

To tease apart the genetic control of preharvest sprouting and emergence, this project has identified about 50 genes/quantitative trait loci (QTL) each for preharvest sprouting tolerance and for seedling emergence in an association mapping population composed of 319 soft white winter wheat breeding lines and released cultivars (Fig. 1). A set of KASP assays were developed allowing us to follow the segregation of molecular markers for these QTL. Statistical models enabling us to use the molecular markers to select for preharvest sprouting tolerance without compromising good emergence were developed (Fig. 2). Based on the original mapping population, it should be possible to select for markers associated with both PHS tolerance and better seedling emergence (Model 2, gold) without losing much prediction accuracy for PHS compared to a Model 1 (grey) selecting for PHS tolerance alone. But the proof is in the pudding – or rather the progeny. The effectiveness of our models and molecular markers will be examined in 369 doubled haploid breeding lines derived from crosses between parents in the original mapping population of 319 SWW lines. The emergence of these lines was characterized last fall in Lind, WA (Fig. 3), and preharvest sprouting tolerance will be characterized this summer using spike-wetting tests. Based on this limited example, it is our hope that we can find the right combination of QTL/genes to have our cake and eat it too - that is to develop good-emerging cultivars with a lower risk of low FN due to preharvest sprouting.

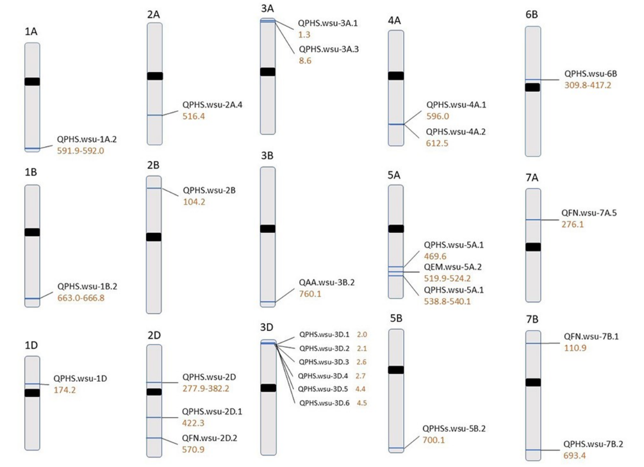


Figure 1. Genetic map of preharvest sprouting (PHS), falling number (FN), and emergence (EM) QTLs. A genome-wide association study using two association mapping populations of 319 and 469 SWW lines, detected over 100 QTLs with 27 of the QTL depicted in the figure. Orange text indicates approximate QTL positions in MBp.

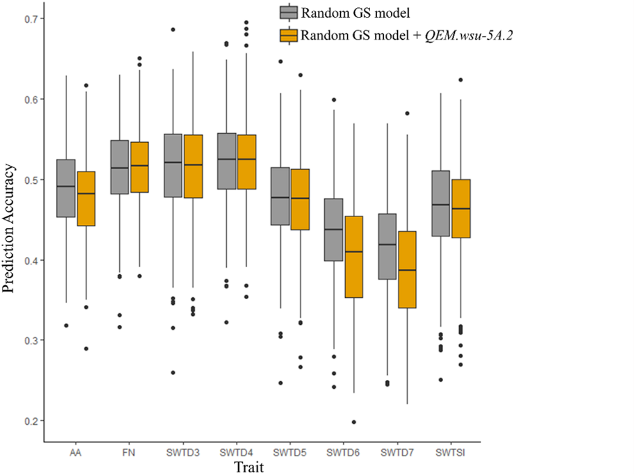


Figure 2. Distribution of prediction accuracies over 500 iterations of cross-validation by trait. Model 1 with markers as random effects (gray) and model 2 with the emergence QTL, *QEM.wsu-5A.2*, used as a fixed effect (gold) are represented.

Figure 3. Field evaluation of fall emergence of plots planted at the Lind Dryland Research Station.

Genomic Selection of Seedling Emergence in a Wheat Breeding Program

LANCE F. MERRICK[1], ARRON H. CARTER[1], AND BRIAN P. WARD[2]
[1]DEPT. OF CROP AND SOIL SCIENCES, WSU; [2]USDA-ARS PLANT SCIENCE RESEARCH UNIT, RALEIGH, NC

In low-precipitation dryland areas, fast-emerging varieties from deep planting are most desirable because rain events before emergence create soil crusting and decrease seedling emergence. Seedling emergence is a vital factor for affecting stand establishment and grain yield and has a poorly understood genetic architecture, which presents a unique opportunity for genomic selection. Genomic selection allows us to create a statistical model using past trait data to predict performance of future breeding lines using genetic data. Seedling emergence relies on environmental influences such as low soil moisture, deep planting, and soil crusting, to create differences in breeding lines for selection purposes. Since these conditions are not present every year at our field screening sites, some years we cannot get good screening for emergence. Using genomic selection to predict and select breeding lines is helpful in years when field observations (called phenotypes) or adequate screening conditions are not possible. The goal of this research is to create a genomic selection model to predict and identify breeding lines with better seedling emergence in our winter wheat breeding program.

In order to create a genomic selection model, we need to use many breeding lines with both phenotypic data for seedling emergence and genetic data. These groups of breeding lines are called training populations. We used two training populations, one consisting of 473 varieties from a diverse quality association mapping panel (QAM) consisting of varieties from various breeding programs and screened from 2015-2019. The other training population consists of 1,876 breeding lines from the Washington State University breeding program from the years 2015-2020. The different populations will be used to compare the diversity panel to the breeding lines for prediction purposes, and to compare whether it would be beneficial to grow independent populations outside of the breeding program for genomic selection purposes. The models use genetic data called genotype-by-sequencing single-nucleotide polymorphism markers, which allow us to collect a large number of genetic markers to account for all of the genes that control seedling emergence. Seedling emergence is also influenced by semi-dwarf varieties commonly used in breeding programs. In order to account for the genes that control the reduced height, we used DNA markers for reduced height (Rht) genes *Rht-B1b* and *Rht-D1b* in our statistical model.

Our preliminary results showed that the prediction model with the highest accuracy was a genomic best linear unbiased prediction model that uses genetic relatedness between breeding lines. Figure 1 shows the results in the QAM, which reached an accuracy of 0.60 in a single year and 0.57 across multiple years. The accuracy of our model is a measure of the genomic selection model to predict the phenotypic observation of a breeding line and ranges from 0 to 1, with 1 being a perfect prediction. Our results showed that predicting seedling emergence in a single year can be high or low, depending on the year we use. However, as we combine years, we gradually increase our accuracy and have a more consistent prediction. Overall, the moderate accuracy of the genomic selection model will aid breeders in identifying breeding lines with better seedling emergence in low rainfall environments and select seedling emergence even in years with little difference between breeding lines due to good field conditions. The breeding lines selected will show better seedling emergence and stand establishment, which will result in higher yield potential.

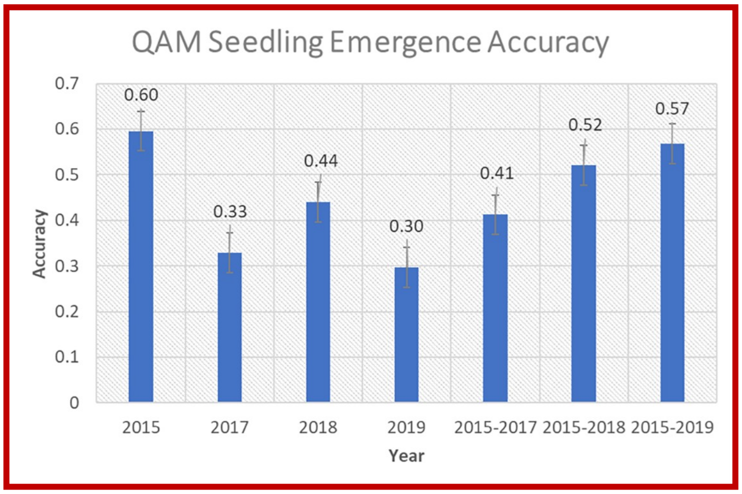


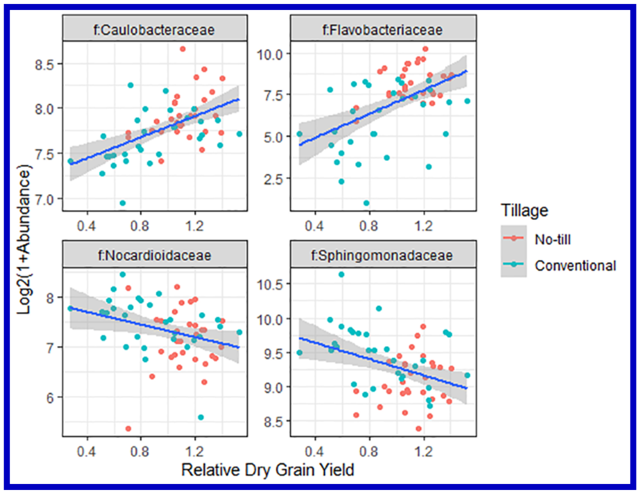
Figure 1. Prediction accuracy for genomic selection models for seedling emergence in the quality association mapping (QAM) population using observations in a single year and adjusted in a combination of years. The inclusion of multiple years of data provides a more consistent result from year to year.

Part 4. Agronomy and Soils

Do Soil Microbes Contribute to Wheat Yield and Soil Health?

DANIEL C. SCHLATTER[1], JEREMY HANSEN[2], BRYAN CARLSON[2], IAN LESLIE[2], DAVID R. HUGGINS[2], AND TIMOTHY C. PAULITZ[1]
[1]USDA-ARS, WHEAT HEALTH, GENETICS AND QUALITY RESEARCH UNIT; [2]NORTHWEST SUSTAINABLE AGROECOSYSTEMS RESEARCH UNIT

Within the last 5 years, there has been an increasing awareness of soil health and its role in crop productivity. Most of this research has focused on soil quality- such things as aggregate stability, organic matter, and bulk density. However, microbes such as bacteria play a key role in plant and soil health, by performing a variety of functions, including N cycling, nutrient uptake, and protection against diseases and abiotic stresses. But there are thousands of species in a single pinch of soil- how do we determine which ones are important? The Cook Agronomy Farm Long Term Agriculture Research site has a history of 20 years of soil information at hundreds of locations, and has both a business as usual and aspirational (no-till) farm. We sampled 120 locations and used next- generation sequencing to determine the complete fungal and bacterial communities. We sampled at two depths, 4 inches and 8 inches. We also did a study looking at the communities down to 5 ft. We also sampled the community over a complete season in 2018-2019. But the most interesting results were found when we took all the soil and yield data from those 120 locations, and tried to correlate yield, organic matter and pH with bacterial families and OTUs. We used the last three years of data in winter, spring wheat, and chickpea rotations. We found at least four groups that were consistently positively correlated with relative yield (Caulobacteraceae and Flavobacteriaceae) and negatively correlated with yield (Nocardiaceae and Sphingomonadaceae). *Caulobacter,* a stalked bacterium, is mostly known from aquatic systems, but very little is known from the soil. *Flavobacterium* is a well-known inhabitant of the wheat rhizosphere, and a potential biocontrol agent. *Norcardia* is an actinomycetes that can survive harsh conditions in the soil with low nutrient levels. It may be more adapted to poor soil conditions with little organic matter, which may be the low yielding sites. Sphingomonads are common in the soil, on plant leaves and on roots. But all these findings are correlative. To show cause and effect, we are trying to isolate these bacteria into culture, so we can test them in the greenhouse to see if they enhance or reduce wheat seedling growth.



Timing of Cover Crop Termination

PACIFIC NORTHWEST WHEAT-BASED SYSTEMS:
Landscapes
in Transition

SAUGAT BASKOTA AND KURTIS SCHROEDER
DEPT. OF PLANT SCIENCES, UI

Interest in cover crops has increased in the Inland Pacific Northwest (IPNW) due to its multiple benefits that include but are not limited to increasing soil health, controlling erosion, building organic matter, and interrupting weed and other pest cycles. In addition, there is a possibility of grazing animals or haying, which has a potential of economic return to the growers. However, there are some issues associated with growing cover crops for grazing or haying. Those include identifying the right cover crop mix and optimal time to graze or bale cover crops. It is crucial that the cover crops are not grown for too long as it might reduce water availability for the following grain/cash crop, especially in dryer areas. The aim of this study is to identify optimal harvest times for maximum forage yield and quality.

To examine the biomass production and forage quality, samples were collected in 2018 at different time intervals from cover crop plots of a multi-year crop rotational study established at St. John, WA and Genesee, ID. The winter annual mix planted at Genesee had winter wheat, sudangrass, proso millet, crimson clover, winter pea, winter lentil, turnip and radish while the spring annual mix at St. John had spring pea, barley, oats, sunflower and turnips. Forage samples were collected approximately every 2 weeks and analyzed to determine protein and fiber content. Crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin and mineral content were measured. The relative feed value (RFV) was calculated, which is an index that uses NDF and ADF and derives a value that can be associated with different quality factors in hay. CP and RFV should be on the higher side and NDF, ADF and lignin should be on the lower side for a good quality forage crop/mix.

All five crop species emerged in the spring mixture at St. John, but in Genesee, only volunteer winter wheat, winter pea and clover survived the winter. The winter mix in Genesee had almost double biomass production compared to spring mix in St. John (Fig. 1). However, the forage quality of cover crops in St. John was superior to the cover crops from Genesee (Table 1), due to the higher ratio of winter wheat in the winter cover crop mix at Genesee. In both locations, there was nearly four-fold increase in biomass production in about 5 weeks, but a corresponding decline in forage quality. The CP content decreased 10% at Genesee over a month and 8% at St. John during the same interval. On the other hand, the fiber content (NDF and ADF) of the mixture increased significantly. The RFV of crops decreased significantly in the latter two sampling dates. The highest RFV was 148 in mid-May at Genesee and 174 in late May at St. John.

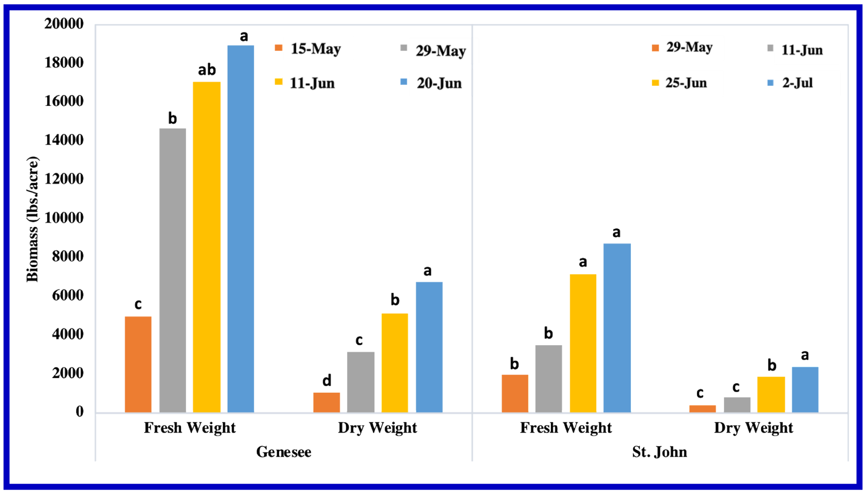


Figure 1. Biomass (fresh and dry) production of winter cover crop mix at Genesee, ID and spring cover crop mix at St. John, WA in 2018.

Preliminary results suggested that time of grazing or baling the cover crops is crucial in terms of nutritional value of the cover crops. Additionally, the forage quality depends on the species composition of the mixture. Based on the preliminary results, we can suggest that the third week of June would be a suitable time to terminate and get optimum production with fairly good quality of forage for haying with the cover crops examined in this study, although results from consequent years would improve this estimate. Grazing could be initiated earlier to provide multiple grazing events during the season depending on the biomass production. Timely termination of cover crops helps to conserve soil moisture for the following grain/cash crops.

LIT is funded through award #2017-68002-26819 from the USDA NIFA (www.pnwlit.org/).

Table 1. Forage nutritive values (CP = crude protein, NDF = neutral detergent fiber, ADF = acid detergent fiber and RFV = relative feed value) of cover crop mixtures at different time period at Genesee, ID and St. John, WA in 2018 compared with forage nutritive values of prime quality hay.

Location	Harvest	Date	CP (%)	NDF (%)	ADF (%)	RFV
	Prime quality hay		>19	<40	<31	>151
Genesee	Harvest 1	15-May	18.0 a	44 c	24 c	148 a
	Harvest 2	29-May	12.3 b	50 b	28 b	126 b
	Harvest 3	11-Jun	8.4 c	52 a	30 a	117 c
	Harvest 4	20-Jun	8.0 c	53 a	30 a	115 c
St. John	Harvest 1	29-May	16.5 a	38 b	22 b	174 a
	Harvest 2	11-Jun	11.9 b	38 b	22 b	177 a
	Harvest 3	25-Jun	10.6 b	48 a	27 a	131 b
	Harvest 4	2-Jul	8.0 c	49 a	26 a	131 b

The WSU Wilke Research and Extension Farm Long-Term Rotation Summary

AARON ESSER AND DEREK APPEL
WSU EXTENSION

The WSU Wilke Research and Extension Farm is located on the eastern edge of Davenport, WA. Washington State University maintains and operates this facility. The farm is in a direct seed cropping system utilizing no-till fallow, winter wheat, spring cereals and broadleaf crops. Broadleaf crops are incorporated when weed pressures and market prices create opportunities for profitable production. The predominant cropping system practiced by farmers in this region is a 3-year rotation, which includes summer fallow, winter wheat, and spring cereals. Farmers are interested in intensifying rotations to reduce fallow years and increase crop diversity to improve long-term agronomic and economic stability.

The south side of the farm is divided into seven plots; three plots are in a traditional 3-year crop rotation that include fallow, winter wheat and spring wheat. Four plots are in an intensified 4-year crop rotation that include fallow, winter wheat, spring broadleaf, and spring wheat. The north side of the farm remains in an intensified rotation that forgoes summer fallow and is in a continuous crop production system. Economic return over input costs (seed, fertilizer, pesticides) is analyzed in three year averages to help remove some of the year-to year variability (Fig. 1). Fixed cost associated with the farm are not included because of the variability from farm to farm across the region. Over the last six years, the 3-year rotation and 4-year rotation have averaged returns above input costs of $104 and $110/acre, respectively, and are not significantly different. The continuous cropping system has averaged $73/acre return above cost during this period and is not significantly different than the 3-year rotation and is less than the 4-year rotation.

More information and reports can be found at http://wilkefarm.wsu.edu/.

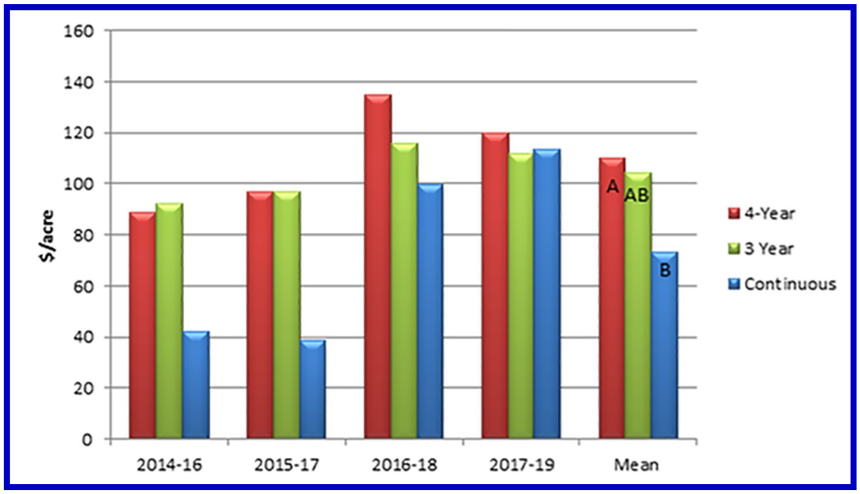


Figure 1. Three-year average economic return over input costs of 3-year, 4-year, and continuous cropping systems at the WSU Wilke Farm. Costs do not include fixed costs associated with the farm. Means within columns assigned different case letter are significantly different (*P*<0.10).

Nitrogen Stabilizers to Improve Nitrogen Use Efficiency in Winter Wheat in High Rainfall Zones of Northern Idaho

SARAH SEUBERT[1], HAIYING TAO[2], AND KURTIS SCHROEDER[1]
[1]DEPT. OF PLANT SCIENCES, UI; [2]DEPT. OF CROP AND SOIL SCIENCES, WSU

In the Pacific Northwest, growers have a constant battle with retaining fall applied nitrogen. For winter wheat in particular, nitrogen use efficiency is at best 50% and nitrogen is susceptible to leaching especially in high rainfall zones, but also can be lost by denitrification in waterlogged soils. The aim of this project is to improve nitrogen use efficiency by use of nitrogen stabilizers with different rates of nitrogen fertilizer in high rainfall zones of northern Idaho and to examine the potential impact of nitrogen stabilizers on the population of nitrifying bacteria.

This project was initiated in the fall of 2019 with field trials in two high rainfall locations: Cavendish, Idaho and Cottonwood, Idaho. Each trial consists of five nitrogen fertilizer rates: 0lbs, 50lbs, 100lbs, 150lbs, and 200lbs of N/acre with and without the nitrogen stabilizer, Instinct® II. The active ingredient of Instinct® II is nitrapyrin, a compound that inhibits the bacterial nitrification of ammonium to nitrate. Soil samples are collected at multiple times throughout the growing season to monitor the fate of applied nitrogen fertilizer. These include late fall when the soil temperature reaches about 32oF to 40oF, early spring as winter wheat breaks dormancy, and then deeper four-foot samples at late tillering to early jointing as well as post-harvest. Each sample will be analyzed for the concentration of ammonium and nitrate. Additional samples also will be taken in the late fall and early spring to examine populations of the nitrifying bacteria *Nitrosomonas* and *Nitrosospira* by quantitative PCR. The project is in its first of two years with the hope of providing additional guidance on the feasibility of using nitrogen stabilizer in rainfed wheat production systems as well as understanding the impact of these stabilizers on populations of nitrifying bacteria.

Wheat Stubble Height Effects on Soil Water Capture and Retention During Long Fallow

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BILL SCHILLINGER[1], DEREK SCHAFER[2], JOHN JACOBSEN[1], STEVE SCHOFSTOLL[1], AND STEWART WUEST[3]
[1]DEPT. OF CROP AND SOIL SCIENCES, WSU LIND; [2]RITZVILLE FARMER; [3]USDA-ARS, PENDLETON, OREGON

A 4-year study was conducted on the Derek Schafer farm near Ritzville, WA, from 2016-2019 to measure the effects of wheat stubble height on overwinter precipitation capture in the soil and subsequent water retention during the dry summer months during 13-month long fallow periods. Soil water measurements were obtained in 6-inch increments to a depth of six feet. All stubble was left undisturbed during the entire fallow period. Treatments were: (i) leave the stubble 30 inches tall after harvest with a stripper header; (ii) cut stubble at 10-inch height; (iii) cut stubble as close to the ground as possible; and (iv) mow the tall stripper-header stubble in mid-June.

On average, the 30-inch and the 10-inch stubble captured significantly more overwinter precipitation than the cut close to the ground treatment ($p<.001$). These overwinter water storage differences were very apparent after the 2017 winter with record-setting heavy snowfall and drifting snow (Table 1). However, from early April until late August, the greatest water loss occurred in the tall stripper-header stubble ($p<.001$), presumably because all stubble was standing and offered less soil shading compared to the 10-inch-tall and close-to-the-ground treatments. Mowing the tall stripper header stubble in mid-June (2018 and 2019 only) did not improve soil water retention during summer compared to the tall stripper-header stubble (Table 1).

In 2019, automated temperature probes that measure multiple depths were driven into the soil with very little soil or residue disturbance. The average 1-inch-depth temperatures over five-day periods were significantly different, with the short-cut stubble remaining about 2 °F cooler than the 10-inch and 30-inch stubble. The mowed-stubble treatment started the summer at a similar temperature to the short stubble, and then warmed to be equal to the 10-inch and 30-inch-tall stubble treatments by the end of August.

Averaged over the four years, the 10-inch and 30-inch treatments were equal for water retention in the 6-foot soil profile and were significantly ($p=0.27$) wetter than with the cut close to the ground stubble by the end of August. Cutting stubble close to the ground was a disadvantage for overwinter precipitation capture, but was equal or better than the other treatments for retaining soil water from April to late August; presumably because this treatment had the most residue lying flat on the soil surface for shading.

Table 1. Total water content (inches) in the six-foot soil profile during the 13-month fallow period after winter wheat harvest as affected by stubble height for four years. Stubble height treatments were: (i) leave 30 inches tall with stripper header; (ii) cut to conventional height of 10 inches; (iii) cut as close to the soil surface as possible; and (iv) mow the tall stripper-header stubble in mid-June (2018 and 2019 only).

	Timing in fallow period				
	Beginning (late July)	Spring (early Apr.)	Over-winter gain	End (late Aug.)	Apr. to Aug. water loss
	Soil water content (inches)				
			2016		
Stripper header	6.01	13.59	7.58 b	10.81	2.79
Cut 10” tall	5.19	13.58	8.40 a	10.86	2.73
Cut close to ground	5.18	13.29	8.12 ab	10.64	2.65
p-value	ns (0.101)	ns (0.392)	0.028	ns (0.710)	ns (0.961)
			2017		
Stripper header	5.29	16.06 a	10.77 a	11.07 b	4.99 a
Cut 10” tall	5.29	15.58 a	10.30 a	12.46 a	3.12 b
Cut close to ground	5.66	12.89 b	7.23 b	11.02 b	1.87 c
p-value	ns (0.384)	< 0.001	< 0.001	0.022	< 0.001
			2018		
Stripper header	9.12	19.62	10.50	16.16	3.46 a
Stripper header - mowed[†]	9.12	19.62	10.50	16.28	3.34 ab
Cut 10” tall	8.11	19.38	11.26	16.47	2.91 ab
Cut close to ground	9.10	19.22	10.12	16.57	2.65 b
p-value	ns (0.205)	ns (0.698)	ns (0.454)	ns (0.806)	ns (0.046)
			2019		
Stripper header	6.58	16.16 a	9.58 a	13.10 a	3.06
Stripper header - mowed	6.58	16.16 a	9.58 a	12.69 ab	3.48
Cut 10” tall	6.36	14.67 b	8.31 ab	12.31 ab	2.36
Cut close to ground	6.07	13.86 b	7.79 b	11.66 b	2.20
p-value	ns (0.566)	< 0.000	0.033	0.005	ns (0.113)
			4-yr avg.[††]		
Stripper header	6.75	16.36 a	9.61 a	12.79 ab	3.57 a
Cut 10” tall	6.24	15.80 a	9.56 a	13.02 a	2.78 b
Cut close to ground	6.49	14.82 b	8.31 b	12.48 b	2.34 b
p-value	ns (0.056)	< 0.001	0.002	0.027	< 0.001

[†] Mowed in mid-June.

[††] 4-yr. average does not include the mowed treatment since only two years of data.

Crop-year precip: 2016 = 14.56”, 2017 = 17.32”, 2018 = 14.59” and 2019 = 12.55” as recorded in Ritzville.

Agroecological Advantages of Early-Sown Winter Wheat in Semi-Arid Environments: A Comparative Case Study from Southern Australia and Pacific Northwest USA

DAVID J. CANN[1*], WILLIAM F. SCHILLINGER[2], JAMES R. HUNT[1], KENTON PORKER[3, 4], AND FELICITY A. HARRIS[5]
[1]DEPT. OF ANIMAL, PLANT AND SOIL SCIENCES, LA TROBE UNIVERSITY, AUSTRALIA; [2]DEPT. OF CROP AND SOIL SCIENCES, WSU; [3]SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE, AUSTRALIA; [4]WAITE RESEARCH INSTITUTE, SCHOOL OF AGRICULTURE, FOOD AND WINE, UNIVERSITY OF ADELAIDE, AUSTRALIA; [5]NEW SOUTH WALES DEPARTMENT OF PRIMARY INDUSTRIES, AUSTRALIA

Wheat is the most widely grown crop in the Mediterranean semi-arid (6-to 15-inch annual) cropping zones of both southern Australia and the inland Pacific Northwest (PNW) of the United States. Low precipitation, low winter temperatures and heat and drought conditions during late spring and summer limit wheat yields in both regions. Due to rising temperatures, reduced autumn rainfall and increased frost risk in southern Australia since 1990, cropping conditions in these two environments have grown increasingly similar. This presents the opportunity for southern Australian growers to learn from the experiences of their PNW counterparts. Wheat varieties with an obligate vernalization requirement (winter wheat), are an integral part of semi-arid PNW cropping systems, but in Australia are most frequently grown in cool or cold temperate cropping zones that receive high rainfall (> 20 inches per year). It has recently been shown that early-sown winter wheat varieties can increase water-limited potential yield in semi-arid southern Australia, in the face of decreasing autumn rainfall. Despite this research, there has to date been little breeding effort invested in winter wheat for growers in semi-arid southern Australia, and agronomic research into the management of early-sown winter wheat has only occurred in recent years. This paper explores the current and emerging environmental constraints of cropping in semi-arid southern Australia and, using the genotype x management strategies developed over 120 years of winter wheat agronomy in the PNW, highlights the potential advantages early-sown winter wheat offers growers in low-rainfall environments. The increased biomass, stable flowering time and late-summer establishment opportunities offered by winter wheat genotypes ensure they achieve higher yields in the PNW compared to later-sown spring wheat. Traits that make winter wheat advantageous in the PNW may also contribute to increased yield when grown in semi-arid southern Australia. This paper investigates which specific traits present in winter wheat genotypes give them an advantage in semi-arid cropping environments, which management practices best exploit this advantage, and what potential improvements can be made to cultivars for semi-arid southern Australia based on the history of winter wheat crop growth in the semi-arid Pacific Northwest.

Download the full paper here: https://www.frontiersin.org/articles/10.3389/fpls.2020.00568/full

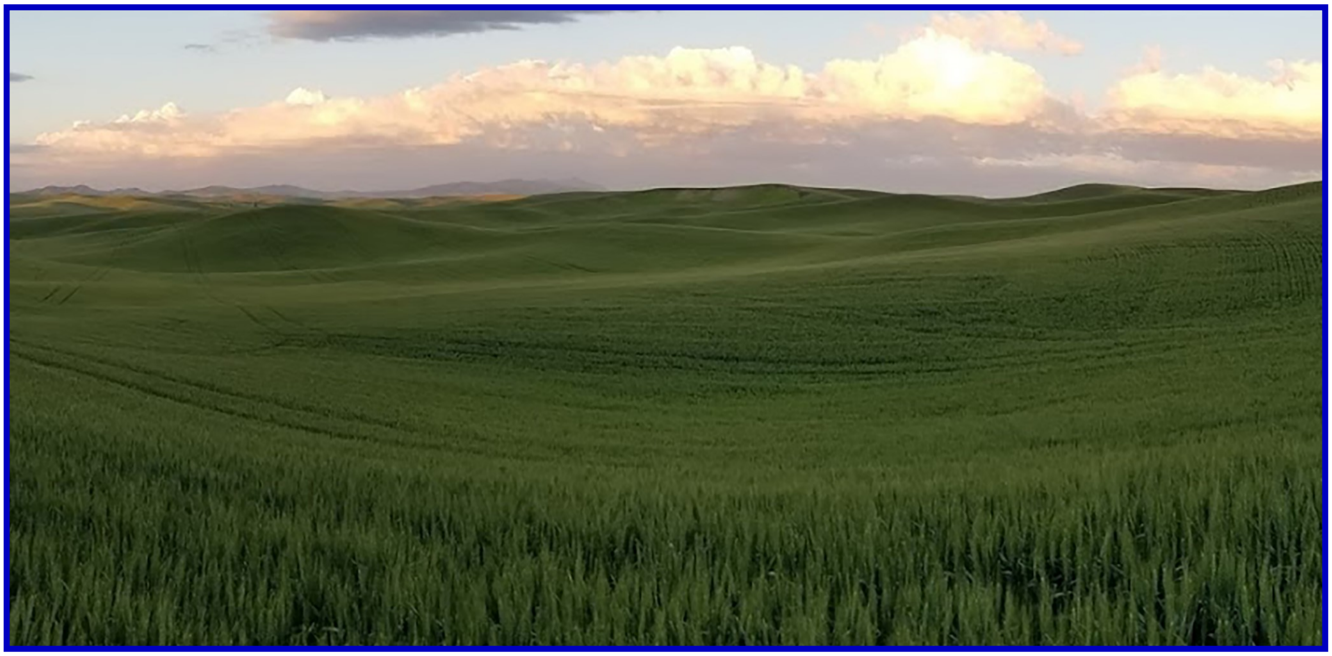
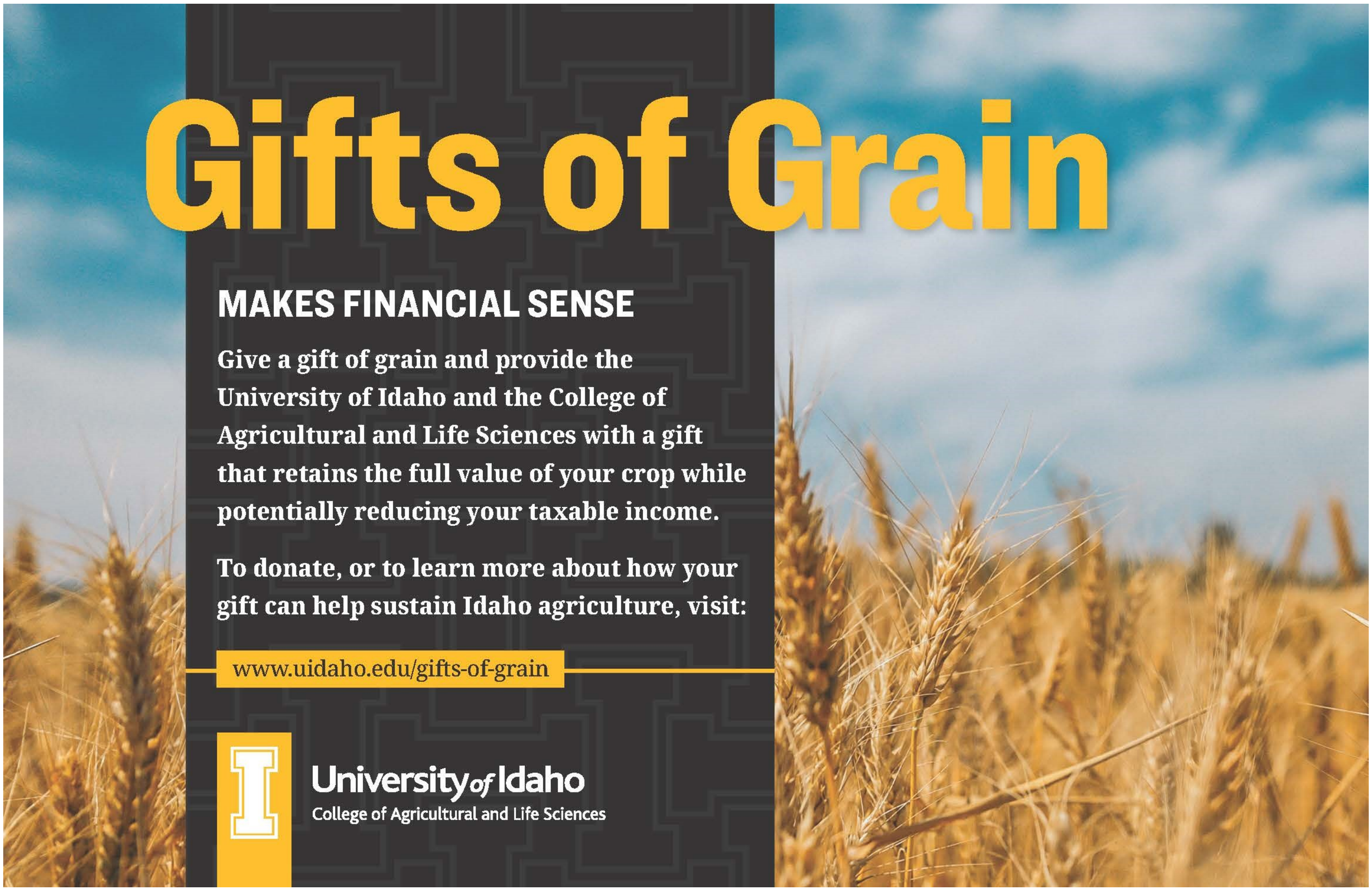
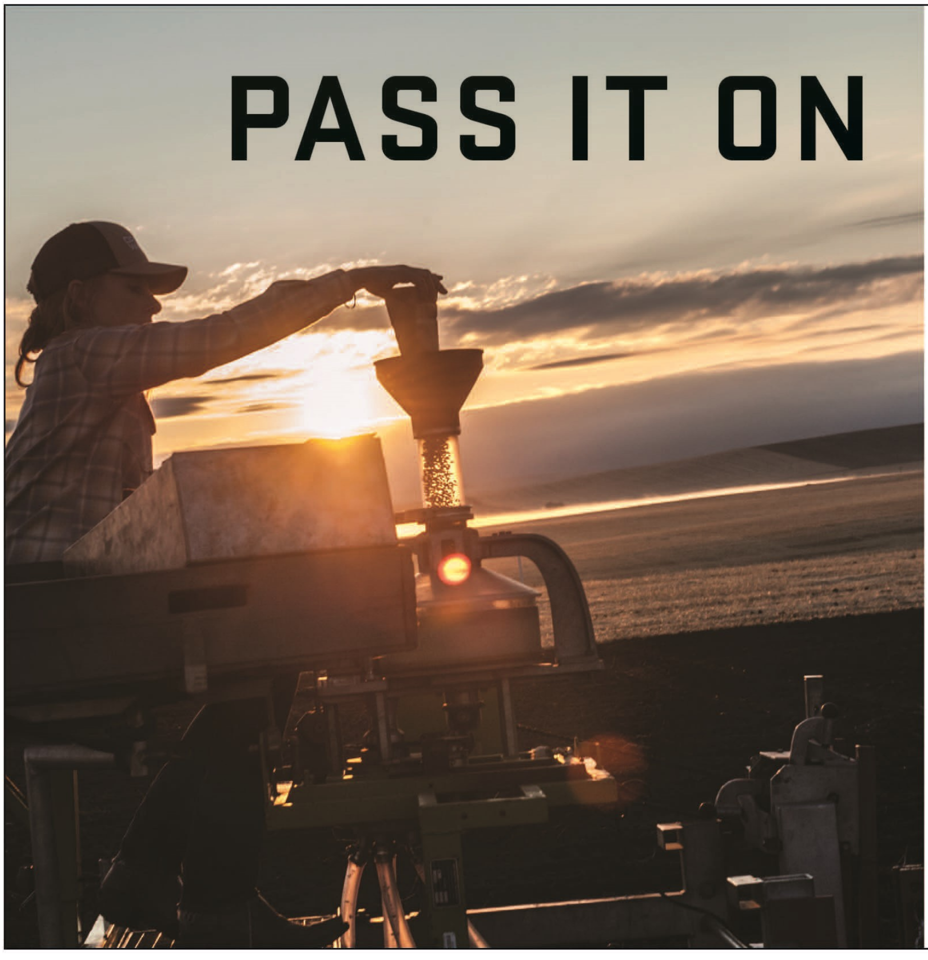


Photo by Karen Sowers





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