COOPERATIVE EXTENSION

Washington State University

Department of Crop and Soil Sciences

Technical Report 99-1

Dedicated to Dr. Edwin Donaldson

1999 Field Day Proceedings: Highlights of Research Progress

Dryland Research Station, Lind
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Stephen Dofing, Editor

Contributing agencies; Washington State University, U.S. Department of Agriculture and Department of Crop and Soil Sciences
Cooperative Extension programs and employment are available to all without discrimination

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Fertilizer, Seed and Amendments

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WA Wheat Commission
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Adams County Wheat Growers
American Malting Barley Assn.
McGregor Company
Whitman County Wheat Growers

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John/Cory Aeschliman	Colfax
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Richard Druffel & Sons	Pullman
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Roger Zaring	Dusty
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HISTORY OF THE DRYLAND RESEARCH STATION

The Washington State University Dryland Research Station was created in 1915 to "promote the betterment of dryland farming" in the 8-to 12-inch rainfall area of eastern Washington. Adams County deeded 320 acres to WSU for this purpose. The Lind station has the lowest rainfall of any state or federal facility devoted to dryland research in the United States.

Research efforts at Lind throughout the years have largely centered on wheat. Wheat breeding, variety adaptation, weed and disease control, soil fertility, erosion control, and residue management are the main research priorities. Wanser and McCall were the first of several varieties of wheat developed at the Lind Dryland Research Station by plant breeding. Twenty acres of land can be irrigated for research trials. The primary purpose of irrigation on the Dryland Research Station is not to aid in the development of wheats for higher rainfall and irrigated agriculture, but to speed up and aid in the development of better varieties for the low-rainfall dryland region.

Dr. M. A. McCall was the first superintendent at Lind. McCall was a gifted researcher given somewhat to philosophy in his early reports. In a 1920 report he outlined the fundamental reasons for an outlying experiment station. He stated: "A branch station, from the standpoint of efficiency of administration and use of equipment, is justified only by existence of a central station". For 83 years, the Lind station has followed the policy of studying the problems associated with the 8-to 12-inch rainfall area.

The facilities at Lind include a small elevator which was constructed in 1937 for grain storage. An office and attached greenhouse were built in 1949 after the old office quarters burned down. In 1960, a 40' x 80' metal shop was constructed with WSU general building funds. An addition to the greenhouse was built with Washington Wheat Commission funding in 1964. In 1966, a deep well was drilled, testing over 430 gallons per minute. A pump and irrigation system were installed in 1967. A new seed processing and storage building was completed in 1983 at a cost of $146,000. The Washington Wheat Commission contributed $80,000 toward the building, with the remaining $66,000 coming from the Washington State Department of Agriculture Hay and Grain Fund. A machine storage building was completed in 1985, at a cost of $65,000, funded by the Washington Wheat Commission.

Growers raised funds in 1996 to establish an endowment to support the WSU Dryland Research Station. The endowment is managed by a committee of growers and WSU faculty. Grower representatives from Adams, Franklin, Benton, Douglas, Lincoln, and Grant counties are appointed by their respective county wheat growers associations. Endowment funds support facility improvement, research projects, equipment purchase, and other identified needs. Also in 1996, the State of Washington transferred ownership of 1000 acres of adjoining land to the WSU Dryland Research Station.

Since 1916 an annual field day has been held to show growers and other interested people the research on the station. This year marks the 83rd field day. Visitors are welcome at any time, and your suggestions are appreciated.

HISTORY OF SPILLMAN FARM

In the fall of 1955, 222 acres of land were acquired from Mr. and Mrs. Bill Mennet at the arbitrated price of $420 per acre. The money for the original purchase came as the result of a fund drive which raised $85,000 from industry and wheat growers. In addition, $35,000 came from the Washington State University building fund, $11,000 from the State Department of Agriculture, and another $10,000 from the 1955-57 operating budget. The dedication of the new facility took place at the Cereal Field Day July 10, 1957. In 1961 the Agronomy Farm was named Spillman Farm after the distinguished geneticist and plant breeder at Washington State University in the late 1880s.

Through the dedicated efforts of many local people and the initiative of Dr. Orville Vogel, arrangements were made to acquire an additional 160 acres north of the headquarters building in the fall of 1961. This purchase was financed jointly by the Wheat Commission and Washington State University. The newly acquired 160 acres were fenced and the wetland drained; it became an integral part of the Agronomy Farm, now consisting of 382 acres.

The headquarters building, which is 140 feet long and 40 feet wide, was completed in 1956. A 100 by 40 feet addition was built in 1981. In 1957 a well that produced 340 gallons per minute was developed. In 1968 the Washington Wheat Commission provided funds for a sheaf storage facility that was necessitated by the increased research program on the farm. At the same time the Washington Dry Pea and Lentil Commission provided $25,000 to build a similar facility for the pea and lentil materials. The facilities of the Spillman Agronomy Farm now range in value well over a half million dollars.

The Spillman Agronomy Farm was developed with proper land use in mind. A conservation farm plan which includes roads, terraces, steep slope plantings, roadside seedings, and a conservation crop rotation including alfalfa and grass has been in use since the farm was purchased.

Dick Hoffman was appointed farm manager in 1994.

PALOUSE CONSERVATION FIELD STATION

The Palouse Conservation Field Station was established as one of 10 original erosion experiment stations throughout the United States during the period 1929 to 1933. The station consists of a number of buildings including offices, laboratories, machine shop, a greenhouse, and equipment buildings, as well as a 60 acre research farm. Scientists and engineers from the USDA/ARS and Washington State University utilize the Station to conduct research projects ranging from soil erosion by wind and water to field-scale cropping and tillage practices in the steep slopes common on the Palouse. Several persons are employed at the Station by both the federal and state cooperators. The Station has a full time manager who lives on site and maintains the busy flow of activities which characterize the farm. This includes the day-to-day routine items, farm upkeep, maintaining the complex planting and harvest schedule to meet the requirements of the various cropping research, and operating the machine shop which fabricates a majority of the equipment used in the research projects. There are also a number of part time employees, many of whom are graduate students, working on individual projects. Along with the many research projects, a no-till project at the Palouse Conservation Farm was initiated on bulk ground in the fall of 1996. The objective of this project is to determine if it is technologically possible and economically feasible to grow crops in the eastern Palouse under no-till. The ARS Units at Pullman are focusing on technologies and research needed to make no-till farming possible in this region.

Table 1. Temperature and precipitation at Palouse Conservation Field Station, Pullman, 1998-99

Month	Monthly Avg. Temperature(F)		Precipitation (in)				
						Deviation from Avg.	
	Max.	Min.	30-Yr Avg.*	Monthly	Total Accum.	Monthly	Accum.
1998							
January	37.5	26.5	2.89	2.05	2.05	-.84	-.84
February	44.6	31.8	2.09	.99	3.04	-1.10	-1.94
March	48.7	32.9	1.96	1.09	4.13	-.87	-2.81
April	56.5	35.9	1.58	.85	4.98	-.73	-3.54
May	63.1	43.0	1.52	3.34	8.32	1.82	-1.72
June	70.7	46.3	1.49	.69	9.01	-.80	-2.52
July	88.4	55.6	.53	1.39	10.40	.86	-1.66
August	87.8	52.6	.95	.49	10.89	-.46	-2.12
September	81.2	48.4	.99	1.24	12.13	.25	-1.87
October	60.1	38.3	1.61	1.04	13.17	-.57	-2.44
November	45.5	35.3	2.64	4.03	17.20	1.39	-1.05
December	34.1	23.4	3.07	5.27	22.47	2.20	1.15
TOTAL			21.32		22.47		1.15
1999							
January	37.6	28.9	2.89	2.02	2.02	-.87	-.87
February	39.5	28.6	2.09	4.12	6.14	2.03	1.16
March	47.7	31.1	1.96	.83	6.97	-1.13	.03
April	54.3	32.2	1.58	.35	7.32	-1.23	-1.20
TOTAL			8.52		7.32		-1.20
1998 CROP YEAR Sept. 1997 thru June 30, 1998			19.84		17.33		-2.51

*Thirty year average for precipitation, 1951-1980

W S U
W
Winter Wheat

1998 Winter Wheat

Stephen S. Jones, Breeder
Steven R. Lyon, Research Technician Supervisor

Growers planted over 2.20 million acres of winter wheat for the 1998 crop year. Madsen, Eltan and Stephens were again the three most popular common white varieties, accounting for almost 70% of the total winter wheat acreage in Washington State. White club was the second most popular class of winter wheat at 9% of the state's total winter wheat. Rely was the most popular variety of white club with 76% of the total for this class. Weston was the most popular hard red, representing 25% of the total hard red acreage for the 1998 crop.

Accomplishments

Yield and disease trials are now being conducted at 23 locations statewide. Seven are in the low rainfall zone (<12"), 8 in the intermediate zone (12-18"), and 8 in the high rainfall zone (>18").

A Cephalosporium nursery was established at Pullman in the fall of 1996. There is currently no chemical control or resistant wheat varieties to combat this disease. From crosses made to wild wheat grasses, approximately 1000 new lines were field-tested and almost 600 exhibited Cephalosporium resistance. The resistant lines are continuing to be tested under severe Cephalosporium infestation and the best selections were entered into preliminary yield trials this fall.

There was essentially no snowmold present in our Mansfield nursery in 1998. This allowed us to evaluate the varieties without snow mold pressure and compare this data to the previous two years when severe snow mold infestation was present.

Mansfield, WA 1996 – 1998

Variety	Snowmold Rating*			Yield (bu/a)			Test Wt. (lbs/bu)		
	98	97	96	98	97	96	98	97	96
Bruehl	-	**5.0**	**5.7**	**62**	**68**	**88**	**56.4**	**58.1**	**57.9**
Sprague	-	5.8	5.0	37	53	77	56.8	61.7	60.6
Eltan	-	4.8	3.5	64	63	73	56.5	55.7	57.8
Edwin	-	**4.5**	**3.3**	**48**	**61**	**63**	**59.8**	**61.0**	**61.3**
Moro	-	4.3	3.2	39	53	55	53.5	60.0	58.3
Tres	-	2.7	2.4	50	35	48	55.0	60.7	59.8
Rely	-	2.8	2.2	49	26	56	55.1	57.0	60.4
Rohde	-	1.5	2.0	48	28	31	58.4	58.3	61.2
Madsen	-	2.7	1.5	40	34	11	53.9	59.5	54.5
Stephens	-	2.0	0.0	24	17	6	48.1	58.5	49.0

*Resistance, higher value better

Results

Bruehl (released 1999): Bruehl has been in 27 field trials the past 3 years and its average yields have exceeded those of Madsen and Eltan across the state. It is considered a potential Eltan replacement for the northern areas of the state. This wheat will give those growers an earlier maturing, stiff straw, snowmold resistant, high yielding club wheat variety. In the snowmold areas it generally outyields Eltan and Sprague while maintaining a similar test weight. Foundation seed should be available in the fall of 2000.

	1996 - 1998 Statewide averages (bu/a)			
	Bruehl	Hiller	Eltan	Sprague
Yield	**78.8**	76.3	70.9	69.1
Test wt.	**57.9**	56.6	58.8	59.2
	1998 mean agronomic/disease characteristics			
Stripe rust	-	+	-	++
Coleoptile	**72.0**	72.6	76.1	73.4
Plant ht.	**35.1**	34.8	35.4	35.5
Heading date	**153**	162	167	160

****

Edwin (released 1998): Edwin, named in honor of the late Dr. Edwin Donaldson, is a tall soft white club (Moro replacement). Edwin has superior straw strength, adult plant stripe rust resistance and emergence that is equal to Moro. Its average plant height is three inches shorter than Moro, has excellent winterhardiness and good snowmold resistance. In the Moro production area from 1996 to 1998, Edwin out yielded Moro by 8.9 bu/a and had a 2.6 lbs/bu heavier test weight. Foundation seed should be available in the fall of 1999.

	1996 – 1998 Moro Production area			
	Edwin		Moro	
	bu/a	Test wt.	bu/a	Test wt.
1998	54.9	60.1	48.4	56.5
1997	68.0	60.6	64.1	59.0
1996	70.1	58.9	53.8	56.5
3 yr. ave.	**64.3**	**59.9**	55.4	57.3

1996 -1998 Hard Red Yield Trials Summary (bu/a)

Variety	1998	1997	1996	3 yr. ave.
WA7869	50.5	63.5	59.5	57.8
Estica	49.2	66.1	-	57.6*
WA7868	46.7	63.5	57.8	56.0
Symphony	51.6	56.6	57.3	55.2
Q. Hyb. 542	47.8	57.8	58.8	54.8
Eltan	45.1	62.7	-	53.9*
Buchanan	44.8	60.5	55.4	53.6
Finley	46.5	61.4	51.6	53.2
Hatton	43.2	55.3	49.2	49.6
Wanser	40.5	48.1	51.3	46.6
Weston	36.4	52.2	50.0	46.2

Locations: Connell, Finley, Prosser, Lind, St. Andrews. *2 year average.

1996 –1998 Soft White Yield Trials Summary
(same varieties: ranked by bu/a across rainfall zones)

Low rainfall

Variety	1998	1997	1996	3 yr. ave.
WA7768	54.1	49.6	69.3	57.7
Hiller	52.1	45.7	60.5	52.8
WA7870	52.3	43.7	58.6	51.5
WA7813	51.1	41.9	60.6	51.2
Eltan	50.7	39.6	61.4	50.6
Rod	50.8	42.0	57.9	50.3
Madsen	54.1	41.4	54.8	50.1
Lewjain	47.4	44.7	57.3	49.8
Sprague	44.1	45.0	59.7	49.6
WA7835	49.3	41.6	57.1	49.3
Daws	47.1	40.5	54.9	47.5
Stephens	48.9	40.1	49.5	46.2

Intermediate rainfall

Variety	1998	1997	1996	3 yr. ave.
WA7768	70.1	86.1	107.3	87.8
Hiller	73.2	74.5	100.1	82.6
Rod	62.9	81.8	102.6	82.4
WA7870	59.7	85.0	100.2	81.6
Lewjain	61.2	78.1	101.9	80.4
Eltan	63.5	82.6	94.9	80.3
WA7813	59.2	78.4	101.0	79.6
WA7835	62.9	73.5	98.8	78.4
Madsen	70.1	64.3	90.9	75.1
Daws	55.0	68.8	93.5	72.4
Sprague	50.2	72.0	85.2	69.1
Stephens	59.8	58.2	85.5	67.8

WSU
W
Winter Wheat

High rainfall

	1998	1997	1996	3 yr. ave.
WA7870	117.3	100.1	135.2	117.5
WA7768	116.0	91.6	136.6	114.7
WA7813	112.4	101.7	129.9	114.7
Rod	110.1	105.1	123.3	112.8
Madsen	113.0	98.0	124.3	111.7
Stephens	107.1	93.4	129.5	110.0
WA7835	102.5	90.8	129.3	107.5
Daws	98.2	90.1	131.0	106.4
Hiller	105.2	92.8	116.2	104.7
Lewjain	95.5	86.0	124.1	101.9
Eltan	94.5	90.0	98.9	94.5
Sprague	83.3	90.1	91.7	88.4

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1998 Variety Testing Program - Winter Wheat

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Overview

The 1998 state winter wheat trial consisted of 33 entries grown at 17 locations. The trial at Moses Lake was irrigated, and the remaining trials were dryland. Trials at Ritzville, Bickleton, Lind, and Coulee City were grown cooperatively with the winter wheat project and the trial at Pomeroy was grown cooperatively with the club wheat breeding project.

Entries consisted of 26 soft white common, 6 soft white club, and 1 hard red common types. Four of the soft white common entries were seed mixtures. In order to obtain a uniform set of comparisons, all entries were grown at all locations. Crop production information, including previous crop, fertility, seeding date, and other factors for the 1998 trials is presented in Table 1.

Growing Conditions

1998 growing conditions were generally excellent for winter wheat production. Yield and crop quality were enhanced by timely rains and above-average temperatures. No significant winter injury was observed at any of the locations. Weather was generally warm and dry during harvest.

Results

Several foliar diseases were present in many of the locations, revealing differential susceptibility among the varieties. Westbred 470 was severely infected with stripe rust at several locations. Cephalosporium stripe was present at some of the nurseries. Footrot diseases were higher at the higher rainfall locations, and resistance to this disease proved beneficial. Among the soft white common wheats, Madsen was the highest yielding entry across all locations, followed by the Madsen-Rod mixture. Hiller was the highest yielding soft white club. Across all market classes Estica, a hard red common wheat, was the top yielding entry.

Acknowledgments

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Table 1. Cultural data for 1998 WSU winter wheat variety trial locations.

Average Annual Rainfall (in)	Nursery Location	Previous Crop	lb Base Fertilizer			Planting								Harvest Date	Soil Type
						Date	Seeding Rate (lb/A)	lb Starter Fertilizer			Planter Type*	Row Space (in)	Soil Moisture** (in)		
			N	P	S			N	P	S					
< 16	Lind	Fallow	40			15-Sep	60				DF	15		22-Jul	Ritzville Silt Loam
	Asotin	Fallow	60		5	7-Oct	90	7	21		DD	6	7.0	4-Aug	Neconda Silt Loam
	Coulee City	Fallow	40			27-Aug	60				DF	15		3-Aug	Timentwa Loam
	Bickleton	Fallow	40			4-Sep	60				DF	15		7-Aug	Broadax Silt Loam
	Lamont	Fallow	70		10	8-Sep	90	7	21		H	9	5.9	27-Jul	Athena Silt Loam
	Creston	Fallow	80		10	9-Sep	90	7	21		H	9	8.3	28-Jul	Bagdad Silt Loam
	Dusty	Fallow	85		12	4-Sep	90	7	21		DD	6	6.4	22-Jul	Onyx Silt Loam
	Ritzville	Fallow	40			10-Sep	60				DF	15		30-Jul	Walla Walla Silt Loam
16-20	Mayview	Fallow	80	12	10	7-Oct	90	7	21		DD	6	7.7	11-Aug	Athena Silt Loam
	Dayton	Fallow	70		12	1-Oct	90	7	21		DD	6	5.7	3-Aug	Athena Silt Loam
	Walla Walla	Garb. Beans	65			14-Oct	90				DD	6		23-Jul	Walla Walla Silt Loam
	Reardan	Fallow	85		5	16-Sep	90	7	21		H	9	9.0	12-Aug	Hanning Silt Loam
	St. John	Fallow	90		15	22-Sep	90	7	21		DD	6	10.4	10-Aug	Athena Silt Loam
> 20	Pullman	Peas	80		10	27-Sep	90	7	21		DD	6	9.0	6-Aug	Palouse Silt Loam
	Fairfield	Lentils	65	10	7	26-Sep	90	7	21		DD	6	5.6	12-Aug	Palouse Silt Loam
	Farmington	Lentils	90		10	26-Sep	90	7	21		DD	6	5.5	26-Aug	Palouse Silt Loam
Irrigated	Moses Lake	Potatoes	180			1-Oct	90				DD	6	pre-irrigated	24-Jul	Warden Sandy Loam

* DF = Deep Furrow: DD = Double Disc; H= Hoe openers

** Inches of moisture in the top 4 ft at all locations except for Asotin where a 3 ft profile was evaluated.

1998 WSU WINTER WHEAT VARIETY TRIAL SUMMARY

September 1, 1998

YIELD (BU/A)

VARIETY	BICKLETON	COULEE CITY	ST. JOHN	LIND DRY	RITZVILLE	DAYTON	LAMONT	WALLA WALLA	DUSTY	CRESTON	REARDAN	FAIRFIELD	ASOTIN	PULLMAN	MAYVIEW	FARMINGTON	MOSES LAKE	VARIETY MEAN
Soft White Common																		
123-T	28.7	45.1	40.4	63.3	62.4	56.8	80.1	76.7	73.4	94.7	97.6	106.7	101.8	74.2	82.5	117.4	141.4	79.0
ALBION (123-M)	38.6	48.5	69.8	79.0	79.9	80.0	91.0	88.6	115.3	108.8	108.4	112.3	104.4	120.1	112.7	130.2	120.9	94.6
BASIN	33.9	36.5	54.8	50.3	63.4	70.0	76.9	99.4	91.9	81.3	107.6	103.0	104.4	107.4	116.9	135.2	134.4	86.3
BRUNDAGE	33.5	51.3	62.2	40.3	73.3	83.8	99.5	60.3	114.5	121.1	102.6	74.1	107.3	109.3	114.4	121.6	153.2	89.5
CASHUP	27.7	39.2	71.2	55.3	65.9	84.4	83.7	101.4	110.0	100.0	118.6	100.5	105.3	100.8	115.3	138.7	138.7	91.6
DAWS	32.2	43.4	58.0	46.9	61.0	72.3	69.4	84.0	75.4	92.3	103.7	105.6	98.9	90.8	106.1	120.6	117.3	81.1
ELTAN	26.6	54.2	35.2	53.2	56.0	64.4	75.2	79.0	54.5	105.5	118.1	87.2	115.4	54.9	88.4	86.2	99.6	73.7
ELTAN-MADSEN 50-50	35.5	50.6	45.6	62.1	78.6	79.7	79.9	99.3	85.0	99.8	110.6	110.3	110.2	116.1	106.5	131.0	136.3	90.4
HILL 81	34.6	42.1	52.4	59.7	59.1	78.6	72.9	105.4	92.1	97.0	105.3	113.2	102.3	99.5	122.8	145.0	143.4	89.7
ID10420A	27.4	44.7	42.0	64.1	60.0	68.6	69.9	100.8	85.0	88.2	107.0	105.5	93.1	113.0	103.1	132.5	156.8	86.0
LAMBERT	41.9	52.2	55.3	70.0	68.8	82.4	93.7	93.5	96.3	112.2	107.3	106.0	101.9	101.2	112.7	121.4	139.7	91.6
LEWJAIN	35.1	46.9	28.5	58.8	60.6	60.7	77.1	74.7	72.3	95.1	108.8	82.2	104.9	55.2	89.4	93.2	105.3	73.5
MACVICAR	16.8	31.2	49.2	66.5	63.8	85.7	58.9	96.1	93.7	86.3	83.1	90.3	76.1	94.3	120.3	135.3	124.8	80.7
MADSEN	45.0	44.5	63.7	71.6	70.3	87.0	99.5	113.3	91.3	105.7	102.9	108.5	105.8	142.8	118.5	146.2	132.2	97.0
MADSEN-ROD 50-50	38.7	42.3	55.4	71.1	72.0	84.9	84.8	101.9	84.9	104.8	103.8	120.8	110.4	111.0	120.7	142.0	152.8	94.3
MADSEN-STEPHENS 50-50	39.6	46.5	61.8	68.1	74.6	83.7	78.7	99.5	97.5	100.5	84.6	112.6	101.0	129.1	117.7	146.5	131.6	92.6
NUGAINES	35.2	41.1	42.5	56.6	53.3	78.8	71.2	82.9	88.0	93.5	98.3	100.6	107.2	84.5	95.9	108.8	106.8	79.1
OR870082	26.8	25.2	77.3	68.3	74.3	90.5	91.3	58.5	118.5	93.0	95.0	82.3	103.9	123.5	115.5	133.5	147.2	89.7
Q.HYBRID 1019	32.4	48.3	55.9	59.4	70.5	88.1	84.7	85.7	104.1	106.5	96.9	95.5	102.1	117.0	123.8	138.3	154.7	92.0
ROD	35.0	44.7	44.4	61.1	65.3	72.9	82.7	84.0	81.3	101.7	111.4	107.2	103.6	92.0	116.7	122.5	120.3	85.1
ROD-WESTBRED 470 50-50	40.2	40.9	48.7	62.5	76.0	88.7	80.5	72.1	86.1	98.2	105.1	111.4	111.7	116.6	117.2	144.9	148.3	91.1
STEPHENS	35.9	44.8	48.0	67.1	70.8	89.3	86.0	86.2	103.3	97.0	78.0	103.0	97.9	95.5	126.2	132.6	124.6	87.4
WA7853	44.7	52.4	42.6	61.2	73.2	76.9	78.0	99.8	90.3	106.4	108.2	96.0	112.4	105.3	115.3	125.4	143.8	90.1
WEATHERFORD (OR898120)	35.6	35.6	53.6	69.6	66.8	83.7	84.1	106.3	105.6	87.6	94.5	114.4	96.6	126.5	122.8	147.3	156.8	93.4
WESTBRED 470	43.4	39.9	58.3	58.7	71.2	91.6	95.1	50.2	92.0	111.2	92.1	97.5	101.5	111.1	120.1	136.5	150.4	89.5
WESTBRED 481	39.4	43.1	57.7	56.5	66.0	91.0	97.8	49.9	93.3	96.1	85.1	112.9	104.2	115.9	130.6	149.3	132.7	89.5
Soft White Club																		
CODA (WA7752)	36.4	44.6	43.0	60.9	68.0	69.8	92.7	82.5	80.4	93.0	108.3	113.2	102.7	82.9	103.2	97.1	112.8	81.9
HILLER	39.9	40.6	43.9	73.1	75.2	75.2	97.4	91.4	94.6	103.3	103.4	92.0	103.6	88.0	114.6	116.0	127.5	87.1
RELY	34.6	45.7	40.7	65.4	71.3	64.7	83.0	81.1	60.9	97.0	99.7	102.9	98.0	65.4	106.6	95.3	118.1	78.3
ROHDE	30.7	38.9	40.1	57.8	62.3	69.0	87.9	75.0	65.3	86.0	94.9	99.8	95.2	82.4	107.4	105.9	130.3	78.2
TEMPLE (OR920054)	37.5	36.5	58.1	68.8	74.8	82.9	89.7	71.1	66.2	91.4	103.6	105.5	96.1	85.1	112.3	102.1	91.7	80.8
TRES	31.4	40.2	38.0	56.1	67.4	50.4	84.1	74.9	53.8	93.9	99.2	96.2	93.0	67.2	92.1	88.1	98.7	72.0
Hard Red Common																		
ESTICA	42.5	47.7	57.7	75.8	89.1	79.0	89.9	116.4	120.4	108.2	107.9	106.8	118.4	121.4	117.8	158.0	170.7	101.6
NURSERY MEAN	35.1	43.3	52.9	62.4	68.6	78.4	84.8	86.1	90.0	98.7	101.2	101.6	102.6	103.0	111.9	126.9	136.5	88.6
CV %	14.1	14.2	27.3	13.0	11.8	8.6	12.8	10.3	14.4	9.5	8.3	12.4	7.6	13.0	5.6	7.9	9.9	26.4
LSD @ .10	6.1	7.2	17.0	9.6	9.5	8.1	12.7	12.1	15.1	11.0	9.8	14.8	9.1	15.8	7.3	11.8	15.8	8.0

Analysis Method - General Linear Models Proceedure

1998 WSU WINTER WHEAT VARIETY TRIAL SUMMARY

September 1, 1998

TEST WEIGHT (LBS/BU)

VARIETY	BICKLETON	COULEE CITY	ST. JOHN	LIND DRY	RITZVILLE	DAYTON	LAMONT	WALLA WALLA	DUSTY	CRESTON	REARDAN	FAIRFIELD	ASOTIN	PULLMAN	MAYVIEW	FARMINGTON	MOSES LAKE	VARIETY MEAN
Soft White Common																		
123-T	55.6	61.7	54.3	60.6	60.4	59.6	60.1	60.3	60.7	61.4	59.0	60.9	59.0	56.6	61.1	59.6	61.1	59.6
ALBION (123-M)	56.0	60.9	54.2	60.3	59.8	59.4	59.7	57.3	60.2	60.9	58.6	60.0	59.1	57.5	59.5	59.1	56.0	58.8
BASIN	56.7	61.9	52.6	61.8	59.9	60.7	61.1	60.3	61.5	61.9	59.8	61.3	60.0	58.0	61.2	59.5	60.9	60.0
BRUNDAGE	56.4	62.0	54.5	63.1	60.5	61.5	61.2	55.1	62.2	62.8	60.3	61.7	60.1	59.0	62.1	59.7	61.1	60.2
CASHUP	56.9	61.5	56.8	61.6	60.2	60.7	60.8	60.5	61.9	62.3	60.6	61.2	59.9	58.9	61.3	60.7	61.1	60.4
DAWS	58.0	62.2	55.2	62.5	60.9	61.1	59.8	59.2	60.8	61.7	60.2	61.3	59.7	56.0	61.0	60.1	59.6	60.0
ELTAN	55.2	60.6	53.3	61.6	59.8	59.8	59.5	58.1	59.2	61.1	58.9	57.4	57.5	51.4	58.1	52.7	57.5	57.8
ELTAN-MADSEN 50-50	55.1	61.0	53.1	61.6	60.3	60.5	59.2	59.8	60.4	60.9	59.1	59.9	58.3	58.5	60.6	58.6	60.3	59.3
HILL 81	56.0	60.8	54.4	62.3	60.3	60.6	58.5	60.6	60.8	61.6	59.4	61.0	58.6	59.1	61.6	60.9	61.6	59.9
ID10420A	56.4	61.6	52.1	61.4	60.3	60.4	58.9	60.1	60.3	61.1	59.3	60.6	58.2	58.7	61.1	59.8	60.6	59.5
LAMBERT	55.4	60.2	53.3	60.8	58.8	59.1	58.2	57.3	59.8	60.7	58.4	60.8	58.6	58.1	60.3	59.5	60.4	58.8
LEWJAIN	57.0	61.9	54.1	63.1	61.8	61.2	61.2	57.3	60.3	61.6	59.5	57.2	58.7	52.7	57.3	54.3	58.7	58.7
MACVICAR	53.6	60.4	51.7	64.6	59.9	60.8	58.0	57.0	60.7	60.4	57.0	58.1	55.5	52.4	59.0	57.7	57.9	57.9
MADSEN	56.4	60.4	56.3	61.2	60.1	60.5	59.9	60.0	60.7	61.1	59.2	60.0	58.5	59.8	61.3	60.5	60.5	59.8
MADSEN-ROD 50-50	56.1	60.1	53.4	60.8	59.4	59.9	59.3	59.2	60.4	60.7	58.5	60.2	58.6	58.5	60.5	59.1	59.7	59.1
MADSEN-STEPHENS 50-50	55.4	60.1	54.4	60.6	59.6	59.5	58.4	56.3	60.3	60.5	57.9	60.6	58.7	59.5	61.0	60.4	60.4	59.0
NUGAINES	57.5	62.3	52.0	62.7	61.0	61.4	61.1	60.3	62.5	63.4	60.3	61.2	59.5	57.8	60.8	58.0	59.9	60.1
OR870082	54.4	58.9	55.7	62.8	60.8	60.5	60.2	58.1	61.8	62.4	58.9	61.7	60.3	61.0	62.3	61.1	62.0	60.2
Q.HYBRID 1019	56.3	61.0	55.9	62.9	60.9	62.1	60.4	60.2	61.7	62.8	58.4	62.3	60.8	62.2	62.1	61.8	62.5	60.9
ROD	55.4	60.3	52.3	61.2	59.1	59.9	58.4	56.4	58.7	60.6	57.9	58.2	57.3	55.2	59.4	57.9	58.7	58.1
ROD-WESTBRED 470 50-50	57.7	62.1	52.6	63.1	61.3	61.9	60.6	57.2	61.8	62.2	58.8	61.4	60.8	59.4	61.9	60.8	61.7	60.3
STEPHENS	54.5	59.9	52.9	60.5	58.5	59.1	57.6	54.6	60.2	60.3	55.9	60.1	58.0	58.3	60.9	59.8	58.3	58.2
WA7853	58.2	61.6	55.3	62.7	61.6	61.9	61.4	60.5	61.6	62.6	60.0	59.6	59.8	56.9	60.4	58.7	60.9	60.2
WEATHERFORD (OR898120)	55.9	60.1	53.1	61.5	60.2	60.7	59.4	59.4	60.6	61.3	58.0	60.9	58.3	59.8	61.6	60.9	61.6	59.6
WESTBRED 470	59.2	63.0	55.3	63.4	62.2	63.0	62.1	57.7	62.9	63.5	59.6	63.2	62.1	62.5	62.9	61.9	63.5	61.7
WESTBRED 481	58.1	62.9	55.3	64.2	62.1	60.8	62.2	56.9	61.4	60.3	58.0	61.2	59.7	59.9	61.8	61.2	59.8	60.3
Soft White Club																		
CODA (WA7752)	58.3	61.5	58.1	61.7	61.0	61.4	61.5	59.2	61.3	61.8	61.3	62.5	60.1	57.5	62.5	59.4	58.6	60.4
HILLER	55.5	57.9	53.7	58.5	57.3	58.2	56.6	55.7	59.0	59.0	57.5	57.4	56.7	54.2	58.7	57.5	56.6	57.1
RELY	56.9	60.3	54.6	60.8	59.7	60.6	59.4	58.2	60.4	61.1	58.8	60.9	58.4	53.3	61.0	56.9	58.2	58.8
ROHDE	57.4	62.1	54.7	61.9	60.5	60.8	60.4	59.1	60.3	61.8	59.2	61.9	60.2	58.5	62.7	60.4	59.0	60.1
TEMPLE (OR920054)	57.4	60.5	56.4	61.3	59.7	60.2	59.0	58.6	59.8	61.8	59.6	61.9	59.4	56.8	61.8	59.2	57.1	59.4
TRES	57.3	61.1	54.6	60.9	60.2	61.6	59.7	57.7	60.4	61.5	59.2	60.7	59.8	55.8	60.8	58.5	56.6	59.2
Hard Red Common																		
ESTICA	53.6	58.9	52.4	58.2	57.9	57.9	57.5	57.8	60.4	59.0	55.7	57.0	55.2	55.3	58.6	57.4	59.8	57.2
NURSERY MEAN	56.4	60.9	54.4	61.7	60.2	60.7	59.8	58.4	60.0	61.5	58.9	60.5	59.1	57.9	60.9	59.4	59.8	59.5
CV %	1.0	1.0	3.7	1.5	0.8	0.6	1.0	1.7	1.2	0.8	1.0	1.5	1.4	1.9	0.8	1.4	2.0	3.1
LSD @ .10	0.6	0.7	2.4	1.1	0.6	0.4	0.7	1.2	0.8	0.6	0.7	1.1	1.0	1.3	0.6	1.0	1.4	0.6

Analysis Method - General Linear Models Proceedure

1998 WSU WINTER WHEAT VARIETY TRIAL SUMMARY

September 1, 1998

PROTEIN (%)

VARIETY	BICKLETON	COULEE CITY	ST. JOHN	LIND DRY	RITZVILLE	DAYTON	LAMONT	WALLA WALLA	DUSTY	CRESTON	REARDAN	FAIRFIELD	ASOTIN	PULLMAN	MAYVIEW	FARMINGTON	MOSES LAKE	VARIETY MEAN
Soft White Common																		
123-T	7.9	8.1	13.4	9.8	9.1	8.6	7.8	11.8	11.6	10.2	9.9	11.1	8.0	10.3	10.0	9.6	11.6	10.0
ALBION (123-M)	8.1	7.7	12.4	9.6	9.4	8.5	7.5	10.9	10.1	9.7	9.8	10.4	7.9	10.4	9.8	9.8	11.2	9.6
BASIN	8.6	8.1	12.6	9.9	9.6	7.9	7.9	10.0	10.4	10.5	9.8	10.4	7.6	10.4	9.9	9.7	10.9	9.7
BRUNDAGE	7.0	7.3	12.6	9.7	8.7	7.9	7.2	11.2	9.7	8.9	9.3	10.6	7.8	9.5	8.8	8.9	10.8	9.2
CASHUP	8.9	8.5	14.0	9.3	9.7	8.8	8.8	10.9	10.4	10.1	10.2	10.4	7.7	10.1	9.4	9.7	11.4	9.9
DAWS	8.4	8.7	12.7	10.1	9.7	8.2	8.5	11.0	10.8	10.1	9.4	10.2	7.7	9.8	9.9	9.2	11.3	9.7
ELTAN	7.4	7.5	13.4	9.7	8.6	8.0	7.7	10.9	10.9	9.9	8.6	10.2	6.4	10.5	9.0	9.4	11.1	9.4
ELTAN-MADSEN 50-50	7.4	8.0	13.9	9.7	9.7	8.8	7.7	11.6	11.0	9.8	9.3	10.0	7.5	10.4	9.9	9.9	11.4	9.8
HILL 81	8.6	7.9	13.9	10.3	9.2	8.6	8.0	11.1	10.8	10.2	9.7	10.2	7.6	9.8	9.9	9.0	11.3	9.8
ID10420A	8.3	8.3	14.1	9.9	9.4	8.1	8.4	10.8	11.5	10.2	9.9	9.8	7.5	8.7	9.0	8.5	10.9	9.6
LAMBERT	7.5	8.1	13.3	9.0	8.4	7.8	7.3	10.9	9.9	9.3	8.9	10.0	8.0	9.4	9.2	9.0	11.1	9.2
LEWJAIN	7.5	7.7	13.7	9.8	9.1	8.5	8.3	11.8	10.8	9.9	8.8	9.9	7.2	10.4	9.7	9.2	11.4	9.6
MACVICAR	9.0	8.5	12.7	8.7	8.6	7.8	8.6	10.7	10.2	9.9	10.3	10.3	7.7	9.6	8.7	8.6	10.6	9.5
MADSEN	8.5	8.6	14.1	9.9	8.9	8.8	8.0	11.8	11.0	10.0	10.1	10.3	7.7	10.7	10.7	10.1	11.7	10.1
MADSEN-ROD 50-50	8.0	7.9	13.5	9.3	8.6	8.2	8.1	11.6	11.2	9.7	9.3	10.4	7.5	10.3	9.9	9.6	11.3	9.7
MADSEN-STEPHENS 50-50	8.1	8.3	13.3	9.3	9.2	7.9	7.7	12.0	11.1	9.9	9.9	10.3	8.2	10.3	9.8	10.2	11.5	9.8
NUGAINES	7.6	7.2	12.3	9.1	8.4	7.7	7.6	10.6	9.8	8.9	8.0	9.4	6.7	9.9	8.5	8.6	11.1	8.9
OR870082	8.7	11.1	13.0	10.2	9.5	8.0	8.2	11.2	10.2	10.2	10.0	11.4	8.2	10.7	10.5	10.1	11.0	10.1
Q.HYBRID 1019	8.0	8.0	13.4	10.0	10.1	7.9	7.9	11.2	11.3	9.5	10.9	11.2	7.8	10.3	9.9	10.3	11.8	10.0
ROD	8.0	7.7	13.0	9.5	8.2	8.3	7.9	11.0	10.5	9.4	9.1	9.7	7.2	9.8	9.3	9.1	11.0	9.4
ROD-WESTBRED 470 50-50	7.4	8.1	13.6	10.7	9.7	8.0	8.2	11.7	10.9	10.0	10.1	10.9	7.9	10.3	10.0	9.9	11.4	9.9
STEPHENS	7.7	8.2	13.1	9.2	8.7	8.3	8.2	11.9	11.0	10.3	10.1	10.8	8.3	9.8	9.7	9.6	11.4	9.8
WA7853	7.4	7.6	13.6	9.4	8.5	7.9	8.1	11.1	10.8	9.1	8.6	9.9	6.8	9.6	9.3	9.0	11.2	9.3
WEATHERFORD (OR898120)	8.4	9.1	14.3	9.7	10.3	8.2	7.9	12.3	11.2	10.6	10.7	10.5	7.9	10.2	9.9	9.9	11.3	10.1
WESTBRED 470	7.0	8.1	13.6	10.3	9.9	8.5	7.5	11.8	10.9	9.7	9.8	11.8	8.1	10.6	10.2	10.7	11.7	10.0
WESTBRED 481	7.7	8.5	13.3	10.6	9.5	7.9	7.9	12.0	10.6	9.9	10.0	10.5	8.0	10.7	10.3	10.1	11.8	10.0
Soft White Club																		
CODA (WA7752)	8.0	8.8	14.2	9.3	7.9	8.6	8.2	12.3	11.1	10.3	9.6	10.2	8.0	10.8	10.2	10.1	12.6	10.0
HILLER	8.7	8.3	13.5	9.1	8.0	7.8	8.1	11.1	10.5	9.2	9.4	10.3	7.5	10.3	9.4	9.4	10.9	9.5
RELY	7.7	8.1	13.7	8.7	8.5	7.8	8.1	11.0	12.1	9.4	9.0	10.2	7.6	10.3	9.2	9.7	11.6	9.6
ROHDE	8.1	9.1	14.3	8.5	9.0	8.3	7.8	11.9	11.7	10.2	10.1	10.7	8.3	10.7	10.2	10.0	11.4	10.0
TEMPLE (OR920054)	7.9	8.2	12.9	9.1	7.8	7.8	7.3	11.0	10.5	10.2	8.8	9.8	8.2	10.0	9.2	9.5	11.7	9.4
TRES	7.6	8.5	13.6	8.6	8.0	9.0	8.1	11.1	12.1	9.4	9.2	9.4	7.8	9.9	8.9	9.2	11.8	9.6
Hard Red Common																		
ESTICA	7.3	7.8	13.0	10.0	9.1	8.4	7.0	11.7	11.2	9.2	10.0	10.5	7.7	10.1	8.9	9.7	11.6	9.6
NURSERY MEAN	8.0	8.2	13.4	9.6	9.0	8.2	8.0	11.3	10.9	9.9	9.7	10.5	7.8	10.2	9.7	9.7	11.5	9.8
CV %	7.6	5.1	4.9	6.7	15.0	8.5	7.3	5.4	6.0	5.7	7.7	5.0	5.2	5.5	4.5	3.9	3.3	13.2
LSD @ .10	0.7	0.5	0.8	0.8	1.6	0.8	0.7	0.7	0.8	0.7	0.9	0.6	0.6	0.7	0.5	0.4	0.5	0.4

Analysis Method - General Linear Models Proceedure

USDA-ARS Wheat Breeding & Genetics

Lynn Little, John Pritchett, Robert E. Allan (ARS collaborator)
and Kay Simmons (ARS Research Leader)
USDA-ARS Wheat Genetics, Quality, Physiology & Disease Research Unit
Washington State University

New Research Geneticist/Breeder

Dr. Kimberly Campbell will be the new ARS club wheat breeder, starting in July 1999. Dr. Campbell has been the Director of the Small Grains Genetics and Breeding Program, Ohio State University. Dr. Campbell's research expertise is in wheat end-product quality, disease resistance and population genetics.

Soft White Winter Wheat Variety Development

Madsen (common) and Rely (club) released from this program continue to be widely grown.

A new club variety Coda (WA7752) with strawbreaker foot rot resistance was released in 1998. Coda also has partial tolerance to Cephalosporium stripe and moderate resistance to leaf rust and powdery mildew. Coda has good club wheat quality that is similar to Rely.

Three club lines (ARS9647, ARS9655, and ARS9658) were advanced to the 1998-1999 Western Regional Performance Nursery to be tested in western states including Washington, Oregon and Idaho. All three club lines have strawbreaker foot rot resistance and out yield Coda.

One soft white common (WA7853) was advanced from the regional trials to the Washington Extension variety trials. WA7853 is high yielding — higher than Madsen, Stephens, Rod and Eltan. This line has resistance to strawbreaker foot rot and has better grain quality than Madsen.

Club Wheats for Dryland Areas

Our objective is to develop club wheats that emerge as well as Moro but that are better than Moro for disease resistance, yield potential and quality. ARS96329 and ARS96342 outyielded Moro by an average of 10% at low rainfall sites in 1996, 1997, and 1998. ARS96329 is being reselected to remove plants containing undesirable glutenin patterns and is a candidate for pre-release in 2000. ARS96343 emerged significantly better than Moro and was an excellent emerger in B. Schillinger's emergence tests in 1996-1998.

Grain Quality Evaluations

Emphasis is being placed on selecting for grain quality prior to preliminary yield testing. The microsedimentation test is being extensively used to screen early generation club lines for end-use quality. Use of this test is reducing the number of lines that are discarded due to poor quality during the labor-intensive yield stages.

Increasing Cold Hardiness in Winter Wheat*

Kay Simmons and John Ray
USDA-ARS Wheat Genetics, Quality, Physiology & Disease Research Unit
Washington State University, Pullman

Goal and Problem

Our goal is to reduce winter kill damage by developing winter wheat varieties with improved winter hardiness. Significant damage was caused by winter kill during the 1998-1999 winter.

New Facilities

Installation of advanced, environmentally-controlled growth rooms in the new WSU Plant Growth Wheat Research Center has markedly enhanced WSU facilities to evaluate cold hardiness levels in wheat varieties. In 1998 five new environmentally controlled growth rooms with the capability to reach freezing temperatures of -22°F (-30°C) were installed. With the new chambers we can now freezing test over 2000 plants simultaneously.

Variety Testing

Freezing tolerance tests have been completed on winter wheat varieties grown in the Pacific Northwest. Relative rankings for cold hardiness of winter wheat varieties have been determined and results have been incorporated into the 1999 Certified Seed Buying Guide, Washington State Crop Improvement Association.

Testing of Multiple Club Wheat Breeding Lines

Initial screening of the 1997 ARS advanced and elite club winter wheat lines has now been completed. Results showed that there are a number of advanced club lines that can survive colder freezing temperatures than any existing club wheat variety. A number of advanced lines that can survive temperatures 2 to 3°F lower than Rely and Coda have been identified. These club wheat lines are now being evaluated for agronomic traits, disease resistance and end-product quality. Freeze testing of the ARS advanced and elite club lines harvested in 1998 are now being completed.

Contact Information: For further information or to visit the cold hardiness research project in the WSU Plant Growth/Wheat Research Center contact Kay Simmons and John Ray at: 509-335-8696 or 335-3632.

*Project is funded by the Washington Wheat Commission

Spring Wheat Breeding and Genetics: Progress Report for 1998

K. Kidwell, G. Shelton, V. DeMacon, B. Barrett, J. Smith and M. Bayram

Overview: Nearly 400 crosses were made in 1998, and early generation soft white, hard red, hard white and spring club germplasm carrying novel Hessian fly and Russian wheat aphid genes were advanced to the field breeding program. F_1 seed from 395 lines was increased to generate segregating progenies for use in conventional breeding strategies, marker-assisted selection and gene linkage analyses. Seed storage protein and polyphenol oxidase analyses were used to select progeny with superior end-use quality potential for advancement. Efforts were initiated to identify potential gene donors for *Rhizoctonia* resistance among wild relatives of wheat, and efforts to determine the feasibility of developing spring wheat hybrids via inter-growth habit cross hybridizations are underway. Approximately 695 F_2 and 610 F_3 families were advanced to the next generation, and 2972 entries among 16,492 F_4 and 23,394 F_5 head rows were selected, based on stripe rust reaction and phenotype, for early generation end-use quality assessment. Approximately 700 lines with superior end-use quality potential will be advanced to 1999 field trials. Over nine hundred (912) F_6, 216 F_7 and 128 advanced lines (F_8+) were evaluated at 3 to 15 locations under annual crop, crop/fallow and irrigated conditions. Grain samples from 474 experimental lines with superior agronomic performance were sent to the Western Wheat Quality Laboratory for milling and baking tests.

Field Breeding Modifications and Early Generation , End-Use Quality Assessment:
A major modification to the field breeding program was implemented in 1998. F_4 head rows were established to accelerate the rate at which entries are evaluated in yield trials by one year, and following the 1999 crop year, all head rows will be composed of F_4 material. As a result of this modification nearly, 40,000 F_4 and F_5 head rows were evaluated in the field in 1998. In comparison, only 12,140 F_5 head rows were evaluated in the field in 1997. Grain from all 1998 head row selections was subjected to early generation, end-use quality assessment.

Following phenotypic selection, grain from selected head rows (~2,800) was visually evaluated for plumpness. Selections with sound grain were separated by market class, then entries from each market class were subjected to a specific assessment strategies depending on end-use goals. Grain protein content (GPC) and grain hardness was determined on whole grain flour using the Technicon (NIR). Microsedimentation and flour swelling volume were used to assess the end-use quality potential of selected lines. The microsed test is used to assess protein quality and gluten strength, whereas the FSV test produces starch swelling values that are highly associated with noodle quality. Polyphenol oxidase levels also were determined for soft white and hard white material to assess noodle color potential before selecting lines to advance to 1999 field trials.

Precision Breeding and Gene Tagging Efforts
A. Enhancing Heterosis of Hybrid Wheat Via Inter-Growth Habit Cross-Hybridizations:
Utilizing heterosis by developing high yielding, hybrid spring wheat cultivars suitable for replacing erosion prone winter wheat production is a viable genetic solution to a major environmental problem. A strategy to enhance grain yield potential of spring cultivars by capitalizing on heterosis between spring and winter wheat germplasm pools via inter-growth habit crosses is described in this proposal. The objectives are to: 1) examine heterotic and maternal effects on F_1 hybrids generated through intra- and inter-growth habit crosses using full diallel analyses;

2) determine the cold hardiness levels of wheat hybrids compared to their inbred parents; 3) assess heterotic and maternal effects on end-use quality properties of F_2 wheat grain; and 4) examine the relationship between targeted DNA marker-based genetic diversity estimates and heterosis in hybrid wheat. Based on previous results, four elite spring and 4 elite winter cultivars were selected as parents for F_1 hybrid synthesis. Since alleles for spring growth habit are dominant, F_1 hybrids of inter-growth habit crosses do not require vernalization to induce flowering. Hybrid seed from a full diallel of crosses among these eight cultivars was synthesized using a chemical hybridizing agent provided by HybriTech Int. Winter hybrid trials were established in the field at two locations in the fall of 1998, and spring hybrid trials were planted at these same locations in the spring of 1999. Inter-growth habit hybrids were fall and spring sown to assess the potential of these varieties as facultative wheats.

B. Evaluating Spring Wheat Cultivars and Alien Triticum Species for Resistance To Rhizoctonia Root Rot: *Rhizoctonia* root rot is a prominent disease of spring cereal grains in direct seed management systems; however, the degree of susceptibility of contemporary spring wheat varieties to this disease is not known. To improve the economic viability of direct seed cereal grain production, an effective, inexpensive method for controlling *Rhizoctonia* root rot must be identified. The most cost-effective method of disease control involves preventing infection through the development of genetically resistant cultivars. This eliminates the need for chemical control measures and increases yield potential by reducing the risk of crop losses associated with the disease. The genus *Triticum* contains nearly thirty species, most of which have been evaluated as potential sources of disease resistance genes for cultivar improvement programs. The objectives of this work are to: 1) Determine whether current spring wheat varieties vary in their natural levels of susceptibility to *Rhizoctonia* root rot; 2) Screen wild relatives of wheat for resistance to *Rhizoctonia* root rot; and 3) Genetically characterize resistance genes for future introgression into cultivated winter and spring wheat varieties.

C. Russian wheat aphid resistance. The availability of DNA markers for genotypic selection of RWA resistance genes would expedite the development of resistant cultivars. This objectives of this study are: I) to determine the inheritance of RWA resistance in four resistant wheat accessions, and ii) to identify DNA tags linked to these resistance genes. RWA screening data, obtained through greenhouse insect trials using F_2 progeny from resistant by susceptible crosses, indicate that one or two genes in each of these lines confer resistance. Linkage analyses are currently underway using RFLP and AFLP markers to assay segregating F_2 progeny. Three candidate DNA tags associated with RWA resistance have been identified to date.

D. Spring growth habit genes. Reciprocal F_2 mapping populations for *Vrn*2 were developed by crossing a near isogenic line carrying *Vrn*2 in a 'Triple Dirk' background to a winter type derived from 'Triple Dirk'. F_2 segregation data for growth habit was collected during the summer of 1998, and phenotypic segregation data will be confirmed using $F_{2:3}$ families during the winter of 1999. Parents of the mapping populations are currently being screened with RFLP and AFLP markers to identify potential DNA tags for linkage map construction.

Variety Releases and Advanced Lines with Potential for Release.

A. Soft White: 'WA7850' was approved for variety release as a replacement for 'Alpowa', 'Penawawa' and/or 'Wawawai'. WA7850 has outstanding grain yield potential and end-use quality properties. This variety is stripe rust resistant, and preliminary data indicate that it also may be resistant to the Hessian fly. The proposed name for this variety is 'Zak', and Breeders Seed will be produced in 1999. Nabisco™ has expressed an interest in Zak for domestic use in the PNW. Grain from a 3 acre grow out will be milled at the ADM facility in Cheney, WA during the fall of 1999 to assess commercial milling performance of this variety, then the flour will be shipped to Portland, OR for commercial baking tests.

B. Hard Red: 'WA7824', a hard red spring wheat with exceptional gluten strength, was approved for preliminary seed increase. WA7824 is resistant to stripe rust and, preliminary results indicate that it may be resistant to the Hessian fly. WA7824 has higher grain yield potential and a higher test weight than 'Westbred 926', however, the grain protein content of WA7824 is slightly lower than Westbred 926. Based on milling and baking data generated by the Western Wheat Quality Laboratory and members of the PNW Quality Council, the end-use quality of WA7824 is superior to that of most hard red spring varieties in commercial production in the PNW. Fertility trials are being conducted to develop management strategies to increase the grain protein content of WA7824. If the Hessian fly resistance is confirmed, WA7824 will be proposed for variety release in 2000.

'Scarlet' hard red spring wheat was approved for final released as a replacement for 'Butte 86' in the semi-arid, non-irrigated wheat production region. Scarlet is moderately resistant to stripe rust, but is susceptible to the Hessian fly. Based on 5 year averages, Scarlet produces from 5 to 10 bu/A more grain than Butte 86 and 'Westbred 926', depending on location. Test weights of grain from Scarlet are 0.5 to 1 lb/bu lower than Butte 86, and are equivalent to Westbred 926. Typically, grain protein contents of Scarlet are similar to or higher than those of Butte 86 in the targeted production region; however, protein contents of Scarlet tend to be 0.4% to 0.6% lower than those of Butte 86 and Westbred 926 when grown in locations receiving more than 14 inches of annual precipitation. Foundation Seed of Scarlet will be available for spring planting in 1999. PVP status of Scarlet is pending.

C. Hard White: For the first time in the history of the spring wheat breeding program at WSU, hard white single plot (138 F_6 lines) and hard white preliminary yield trials (21 F_7 lines) were established in 1998. All hard white breeding material in the program was prescreened for high molecular weight glutenins and tyrosinase or L-DOPA reaction prior to field evaluation. One advanced experimental line appears to have higher grain yield potential and superior milling quality compared to Idaho377s. If the superiority of this line (S9700020) is confirmed, it will be proposed for release in the year 2001.

D. Spring Club: Sixteen advanced generation (F_7) spring club experimental lines were evaluated in replicated yield trials at three locations in 1998. Four lines had outstanding grain yields and end-use quality properties compared to 'Calorwa'. Following evaluation in agronomic trials in 1999, the best entry among these lines will be proposed for variety release in the year 2000 or 2001, depending on seed availability.

1998 Variety Testing Program - Spring Wheat

S. Dofing, K. Kidwell, E. Donaldson†, P. Reisenauer, G. Shelton, V. DeMacon
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Overview

The 1998 state spring wheat trial consisted of 42 entries grown in 16 trials at a total of 15 locations. Entries consisted of 17 soft white common, 1 soft white club, 17 hard red common, 5 hard white common, and 2 spring durums. Both a summer fallow and annual cropping trial were grown at Lind. Trials at Fairfield, Pullman, Pomeroy, Ritzville, Lind, and Royal Slope were grown cooperatively with the spring wheat breeding program. Trials at Moses Lake and Royal Slope were irrigated, and the remaining trials were dryland. The soft white wheat ML409015 and the spring durums Kronos and NPB871104E were grown only under irrigation at Moses Lake and Royal Slope. Crop production information, including previous crop, fertility, seeding date, and other factors for the 1998 trials is presented in Table 1.

Growing Conditions

All trials were planted in a timely manner into excellent soil moisture. High temperatures during the grain filling period caused a reduction in test weight. Severe stripe rust infection levels were detected in several nurseries including Ritzville, Lamont, Reardan, Fairfield, Dusty, St. John, Farmington, and Pullman. Severe Hessian fly infestation occurred at Bickleton and, as a result, resistant varieties were among the highest yielding entries at this location. Excessive surface residue at Pomeroy hindered stand establishment there, which resulted in low test weights and high protein contents. Thus, data from 1998 may not be indicative of performance under more typical conditions. Heat and moisture stress at Moses Lake resulted in yield and test weights that were well below average for this irrigated site.

Results

Spring wheat yields were generally excellent in 1998. Among named varieties, Alpowa, Edwall, and Wakanz were the highest yielding soft white common varieties across all locations. Express, Jefferson, and Scarlet were the highest yielding named hard red common varieties. Protein values were not especially high in 1998, probably due to the generally high grain yield. The only hard red common wheat with protein greater than 13% was the unadapted, low yielding variety Kulm.

Acknowledgments

This work was made possible by funding provided by the Washington Wheat Commission, WSU College of Agriculture and Home Economics, Washington State Crop Improvement Association, fees paid by private companies, and the generous contribution of cooperators who provided land and other assistance required to grow these trials.

Table 1. Cultural data for 1998 WSU spring wheat variety trial locations.

Average Annual Rainfall (in)	Nursery Location	Previous Crop	lb Base Fertilizer			Planting								Rainfall after planting (in)	Harvest Date	Soil Type
						Date	Rate (lb/A)	lb Starter Fertilizer			Planter Type*	Row Space (in)	Soil Moisture** (in)			
			N	P	S			N	P	S						
< 16	Lind Annual	Spring Wheat	60	30	20	6-Mar	60	4	14	0	DD	6	5.0	2.8	28-Jul	Ritzville Silt Loam
	Lind Fallow	Fallow	20	30	20	6-Mar	60	4	14	0	DD	6	6.3	2.8	27-Jul	Ritzville Silt Loam
	Bickleton	Winter Wheat	40	0	10	22-Apr	60	4	14	0	H	8	4.0	2.0	20-Aug	Broadax Silt Loam
	Horse Heaven	Winter Wheat	30	0	0	22-Feb	60	7	21	0	DD	6	6.7	2.5	23-Jul	Warden Silt Loam
	Lamont	Winter Wheat	60	15	0	1-Apr	70	7	21	0	DD	6	6.6	3.3	18-Aug	Athena Silt Loam
	Dusty	Winter Wheat	82	12	3	18-Mar	70	7	21	0	DD	6	5.5	6.3	7-Aug	Onyx Silt Loam
	Ritzville	Winter Wheat	70	0	8	19-Mar	60	4	14	0	DD	6	5.5	4.9	19-Aug	Walla Walla Silt Loam
16-20	Pomeroy	Spring Wheat	70	0	10	6-Apr	70	4	14	0	H	8	5.8	4.9	18-Aug	Athena Silt Loam
	Dayton	Winter Wheat	65	0	0	9-Apr	80	7	21	0	DD	6	6.5	6.5	13-Aug	Athena Silt Loam
	Reardan	Winter Wheat	75	0	5	17-Apr	80	4	14	0	H	8	8.0	5.7	21-Aug	Hanning Silt Loam
	St. John	Winter Wheat	70	10	0	15-Apr	80	7	21	0	DD	6	8.7	9.0	18-Aug	Athena Silt Loam
> 20	Pullman	Peas	85	30	20	8-Apr	80	4	14	0	DD	6	6.9	6.8	11-Aug	Palouse Silt Loam
	Fairfield	Winter Wheat	85	0	0	13-Apr	80	4	14	0	DD	6	9.0	5.9	20-Aug	Palouse Silt Loam
	Farmington	Winter Wheat	90	0	0	20-Apr	80	7	21	0	DD	6	9.8	8.5	27-Aug	Palouse Silt Loam
Irrigated	Royal Slope	Corn	80	0	30	18-Mar	90	0	0	0	DD	6	pre-irrigated	n/a	4-Aug	Neppel Sandy Loam
	Moses Lake	Sugar Beets	120	0	12	10-Mar	90	0	0	0	DD	6	pre-irrigated	n/a	25-Jul	Warden Sandy Loam

* DD = double disc drill; H= Hoe openers

** Inches of moisture in the top 4 ft at all locations except for Bickleton where a 3 ft profile was evaluated.

1998 WSU SPRING WHEAT VARIETY TRIAL SUMMARY
YIELD (BU/A)

VARIETY NAME	BICKLETON	HORSE HEAVEN	LIND ANNUAL	POMEROY	DAYTON	LIND FALLOW	RITZVILLE	LAMONT	REARDAN	FAIRFIELD	DUSTY	ST. JOHN	FARMINGTON	PULLMAN	MOSES LAKE	ROYAL SLOPE	VARIETY MEAN
Soft White Common																	
ALPOWA	26.6	31.2	34.3	55.4	49.7	56.4	60.1	66.8	62.4	59.7	70.5	70.1	69.9	70.3	86.2	120.9	61.5
BZ 692-108	25.8	33.9	30.2	50.6	53.8	56.6	60.4	68.7	68.8	66.8	68.9	75.2	79.8	76.1	82.3	132.6	64.1
EDWALL	26.3	30.0	34.2	50.7	47.0	57.1	59.6	63.2	66.8	66.0	70.2	70.9	69.2	59.3	83.9	130.3	61.2
FIELDER	20.8	29.0	32.1	41.1	47.8	53.0	46.8	52.1	47.1	34.7	59.3	49.6	55.2	36.0	77.8	107.3	48.9
ID505	24.0	28.8	37.2	52.9	52.8	55.8	63.2	68.2	62.1	62.1	70.6	72.2	75.0	79.7	82.6	125.0	63.0
ID506	21.9	32.9	29.7	52.6	51.7	52.2	57.1	70.3	68.3	82.5	63.8	76.2	84.0	73.6	87.2	124.2	63.9
ML409015	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	112.7	112.7
PENAWAWA	27.2	28.4	30.8	45.1	51.3	53.8	53.9	59.6	63.4	55.0	69.6	64.3	69.4	62.7	90.4	127.1	59.0
POMERELLE	19.5	32.9	28.8	38.1	52.1	49.3	51.6	59.9	52.3	51.4	63.4	64.0	68.6	62.7	72.3	121.9	55.3
VANNA	26.7	28.8	33.9	43.9	53.5	53.8	50.9	57.6	63.7	50.9	63.1	60.4	70.5	53.8	93.3	119.4	57.2
WA7850	30.8	29.4	33.0	45.5	51.0	49.4	59.7	71.0	66.7	71.9	66.7	76.1	74.6	89.6	76.5	132.5	63.8
WA7851	25.6	32.0	32.5	48.2	51.9	51.9	57.9	61.3	63.6	70.9	68.2	70.2	75.8	78.7	92.3	127.8	62.6
WA7862	24.9	32.6	31.1	45.6	49.1	50.1	47.9	58.9	53.8	52.7	66.6	62.5	70.4	63.7	66.8	108.4	55.1
WA7864	23.5	28.3	30.1	48.1	46.3	54.7	58.8	60.0	66.5	63.6	70.5	75.6	72.2	67.1	82.7	119.6	60.1
WAKANZ	28.1	29.6	35.7	50.5	50.4	57.2	63.3	65.0	57.6	66.0	67.7	68.0	67.8	70.4	90.1	121.0	61.3
WAWAWAI	29.3	28.1	29.5	44.9	51.3	49.0	50.8	64.9	69.0	64.6	65.9	74.6	72.2	72.3	73.3	107.0	58.9
WHITEBIRD	24.0	28.0	32.7	45.3	52.1	49.2	53.8	62.7	58.2	57.6	67.5	68.1	73.4	69.3	86.8	114.1	58.5
Soft White Club																	
CALORWA	22.1	14.6	26.1	45.7	47.7	51.0	61.4	61.9	60.9	70.7	62.5	65.0	80.0	73.0	71.7	106.1	57.3
Hard Red Common																	
BUTTE 86	21.4	20.4	27.8	45.5	45.9	50.3	44.9	51.9	52.3	56.0	57.1	63.0	63.7	60.5	84.9	107.0	52.8
EXPRESS	20.5	22.7	36.0	49.3	51.0	57.2	61.3	52.6	59.8	72.0	61.3	65.3	66.6	77.6	96.9	120.0	60.1
JEFFERSON	27.3	27.2	34.2	46.2	56.6	55.8	60.6	56.1	62.3	70.5	67.6	72.8	74.6	71.6	97.8	109.3	61.4
KULM	18.7	23.2	26.4	45.5	43.0	45.5	42.9	47.8	51.1	55.0	58.4	57.6	62.6	66.4	81.0	93.4	50.7
NW#10	24.4	27.2	31.8	45.5	51.9	52.7	53.9	53.0	59.1	67.4	56.1	62.7	69.1	76.1	70.7	110.8	56.8
SCARLET (WA7802)	23.1	29.7	29.4	45.8	56.4	50.6	54.2	56.5	66.3	68.6	69.5	64.6	70.8	73.1	83.0	113.5	59.3
SPILLMAN	20.9	26.8	26.8	45.3	46.2	52.2	53.3	49.8	55.8	66.9	57.5	66.1	75.9	71.5	80.1	111.0	56.3
WA7824	26.9	26.3	28.4	48.0	51.2	53.2	59.0	61.1	62.8	77.0	62.2	70.4	75.4	85.3	89.7	111.7	61.4
WA7839	26.4	23.2	33.8	48.4	58.3	52.6	61.1	51.5	61.4	74.1	64.2	71.1	74.0	81.7	89.1	104.2	60.5
WA7840	29.0	20.2	27.2	42.5	49.5	51.1	46.9	51.5	62.2	66.7	59.9	67.9	71.0	71.6	90.1	111.2	56.9
WA7841	27.5	27.6	32.8	42.6	49.0	52.9	56.7	59.5	58.3	76.7	59.6	67.0	69.4	81.1	82.3	123.1	60.0
WA7842	26.9	26.2	32.0	43.3	49.4	51.0	54.8	51.0	62.8	71.9	62.3	64.3	68.5	77.3	82.7	118.5	58.6
WA7845	28.2	29.0	31.7	45.0	54.9	52.3	54.1	46.7	60.3	65.2	70.5	64.9	65.9	75.2	76.8	111.5	58.0
WA7858	28.8	27.5	31.9	43.6	51.0	52.2	49.9	54.6	65.9	66.7	62.9	72.6	67.2	69.7	91.4	107.8	58.5
WPB 926	26.6	21.3	31.9	46.2	51.4	50.8	61.6	53.8	58.2	66.9	64.3	71.5	71.3	79.5	83.3	106.8	58.7
WPB 936	24.8	23.0	34.4	47.7	54.5	51.3	59.7	57.9	62.6	66.4	67.9	72.0	69.5	74.1	73.0	105.8	58.8
WPB87331	26.5	18.6	28.2	54.2	56.4	51.2	43.1	54.9	62.1	55.6	58.4	71.6	79.2	53.0	97.8	105.8	56.7
Spring Durum																	
KRONOS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	96.3	96.3
NPB871104E	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	126.4	126.4
Hard White Common																	
ID377S	22.8	26.9	28.0	44.0	49.9	50.2	48.8	65.5	59.5	59.0	67.4	69.8	73.1	77.3	80.7	116.0	58.3
ID523	14.4	22.2	35.1	43.7	49.0	52.9	59.7	61.9	54.1	59.6	67.0	68.0	73.4	76.4	84.9	130.0	59.1
ID533	25.7	29.6	29.3	39.8	54.9	55.0	51.8	69.2	62.9	71.3	72.5	72.2	80.7	79.2	80.1	136.3	62.9
ML107455	21.3	26.3	35.0	45.9	52.1	48.8	60.4	72.1	65.6	74.7	68.6	75.1	69.8	87.8	79.1	131.1	63.1
OR870453	15.8	29.7	35.3	45.9	51.3	54.2	60.9	68.6	55.7	71.1	62.1	65.7	78.1	77.5	91.4	124.9	61.3
NURSERY MEAN	24.5	27.0	31.5	46.4	51.1	52.4	55.3	59.5	60.8	64.8	64.9	68.2	71.7	71.8	83.7	116.4	59.3
CV %	15.8	18.3	10.8	10.1	9.7	7.6	6.0	11.0	7.3	6.8	7.2	6.1	10.7	5.6	8.0	7.7	8.9
LSD @ .10	4.5	5.8	4.0	5.5	5.8	4.6	3.9	7.7	5.2	5.2	5.5	4.9	9.0	4.7	9.1	10.6	2.2

Analysis Method - General Linear Models Proceedure

1998 WSU SPRING WHEAT VARIETY TRIAL SUMMARY
TEST WEIGHT (LBS/BU)

VARIETY NAME	BICKLETON	HORSE HEAVEN	LIND ANNUAL	POMEROY	DAYTON	LIND FALLOW	RITZVILLE	LAMONT	REARDAN	FAIRFIELD	DUSTY	ST. JOHN	FARMINGTON	PULLMAN	MOSES LAKE	ROYAL SLOPE	VARIETY MEAN
Soft White Common																	
ALPOWA	60.0	62.3	56.7	56.9	58.9	59.1	60.2	59.3	61.3	61.5	59.3	59.2	60.1	59.1	58.4	62.9	59.8
BZ 692-108	56.7	60.6	57.5	53.6	57.1	58.0	59.9	58.8	59.4	59.4	57.7	57.8	59.7	59.6	55.5	62.7	58.5
EDWALL	53.8	59.7	56.3	51.6	55.3	55.9	58.9	57.7	56.6	58.0	56.0	56.7	57.6	57.1	53.2	60.7	56.8
FIELDER	57.1	60.9	57.2	53.6	57.8	58.1	59.1	57.8	57.8	56.2	56.9	56.1	57.5	56.4	56.7	61.2	57.6
ID505	58.6	61.9	58.7	59.5	59.0	59.5	60.1	59.8	59.9	60.1	59.0	59.1	60.3	60.3	54.7	62.3	59.8
ID506	57.1	60.8	56.7	56.3	56.4	57.2	57.8	58.5	59.5	59.5	57.8	57.5	58.7	59.0	55.5	61.4	58.2
ML409015	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	60.1	60.1
PENAWAWA	57.1	61.1	58.2	54.4	58.0	59.3	60.4	60.1	60.3	59.5	59.1	58.7	59.5	60.2	57.0	62.9	59.2
POMERELLE	56.2	60.6	56.0	52.6	57.6	55.6	58.8	59.0	58.1	58.1	57.6	57.0	59.2	58.0	53.5	60.7	57.6
VANNA	56.3	60.6	55.6	54.2	57.5	56.7	57.9	57.7	58.7	58.5	56.9	56.4	57.5	57.2	54.9	61.7	57.5
WA7850	58.0	61.3	58.0	55.8	57.8	57.6	59.1	58.9	58.8	60.0	57.8	57.7	60.0	60.1	54.3	61.8	58.8
WA7851	59.0	62.4	60.5	57.4	59.9	60.3	60.7	60.4	61.1	62.1	60.5	59.9	60.8	61.3	58.7	63.1	60.6
WA7862	57.0	61.4	58.9	56.1	58.2	57.1	58.5	59.1	57.9	59.3	57.6	58.5	58.6	59.2	53.4	60.6	58.5
WA7864	55.1	61.0	58.2	54.8	55.1	58.3	59.3	58.3	58.3	59.3	57.3	57.9	58.4	58.9	54.6	62.3	58.1
WAKANZ	56.2	60.7	56.9	56.6	57.8	58.0	58.2	58.6	58.9	59.3	57.7	57.4	58.3	57.5	56.0	61.6	58.2
WAWAWAI	59.1	62.1	58.9	56.0	59.5	58.6	60.8	60.5	61.3	61.3	59.3	59.8	60.5	61.9	55.5	63.4	60.1
WHITEBIRD	57.8	61.6	57.5	54.4	57.8	58.3	59.6	60.0	58.8	58.4	58.9	58.5	59.5	59.1	58.5	62.2	58.8
Soft White Club																	
CALORWA	56.9	60.2	58.9	54.6	57.6	58.8	59.3	59.5	59.8	59.8	59.0	57.6	58.9	59.1	56.4	61.1	58.7
Hard Red Common																	
BUTTE 86	58.6	60.5	58.0	59.3	59.2	59.4	60.0	60.3	60.9	62.1	58.6	60.3	61.0	61.9	59.1	63.3	60.2
EXPRESS	57.2	60.6	58.5	57.5	58.6	59.1	60.5	60.3	60.6	61.3	59.6	60.3	61.3	61.7	56.0	62.5	59.9
JEFFERSON	58.5	62.1	59.1	58.6	58.8	59.7	60.6	60.1	59.5	60.5	59.8	59.8	60.3	60.0	59.0	63.1	60.0
KULM	60.4	62.4	60.4	60.9	60.6	61.4	61.8	61.4	62.0	63.4	61.0	61.7	62.5	63.6	61.3	63.9	61.8
NW#10	55.3	59.0	55.0	52.2	55.5	56.0	58.0	56.7	56.2	56.9	53.6	56.4	56.7	57.3	48.5	58.9	56.1
SCARLET (WA7802)	57.4	61.2	59.2	55.4	58.7	57.9	60.3	59.5	59.9	60.4	58.9	59.0	60.3	60.9	56.1	62.8	59.4
SPILLMAN	55.0	60.7	58.4	53.3	56.9	57.0	58.5	58.7	58.9	59.4	58.2	58.1	59.2	59.9	53.5	62.6	58.3
WA7824	59.7	61.6	59.8	57.3	57.8	59.3	61.3	60.2	61.0	61.9	58.8	60.4	61.7	61.9	57.1	62.3	60.3
WA7839	59.3	61.7	59.7	58.1	59.2	60.6	61.1	60.2	60.4	61.1	60.9	60.0	60.8	61.8	57.3	62.9	60.5
WA7840	59.2	60.5	59.1	57.4	59.6	59.9	60.9	60.9	61.1	62.1	60.1	60.8	61.8	62.4	59.3	63.8	60.6
WA7841	57.3	60.1	58.4	53.0	57.3	57.2	59.1	58.8	58.2	59.3	57.3	58.0	59.0	59.6	51.6	61.7	58.2
WA7842	57.1	59.7	58.1	54.1	57.6	57.2	59.1	58.6	58.5	59.1	56.8	57.5	58.3	59.6	51.2	61.6	58.1
WA7845	59.2	62.5	61.1	57.2	60.0	60.3	61.2	60.6	61.0	61.3	60.7	59.7	61.1	62.4	53.2	63.0	60.6
WA7858	58.1	62.1	58.4	57.8	58.6	59.5	60.4	60.5	61.1	61.8	60.0	61.0	60.9	62.9	58.0	64.1	60.4
WPB 926	58.1	60.9	58.1	56.4	58.2	59.3	60.2	59.8	59.6	60.0	59.2	59.3	58.9	60.9	55.8	62.5	59.4
WPB 936	58.0	61.8	59.7	56.0	59.3	59.5	60.9	60.5	59.7	60.1	59.3	59.3	60.1	60.1	57.5	62.4	59.7
WPB87331	56.6	57.8	57.1	57.3	58.1	59.1	59.4	58.9	60.1	60.0	59.3	58.6	59.8	59.3	58.2	62.5	58.9
Spring Durum																	
KRONOS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	62.2	62.2
NPB871104E	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	61.6	61.6
Hard White Common																	
ID377S	57.7	62.1	59.0	56.6	60.6	57.9	60.8	61.0	61.0	62.0	58.7	59.5	61.7	62.3	56.1	63.2	60.2
ID523	56.4	60.5	56.5	54.6	57.5	58.4	59.3	59.1	58.4	59.3	56.4	57.6	58.2	59.6	55.2	61.2	56.8
ID533	57.9	62.7	59.6	56.5	61.0	59.6	60.9	61.4	61.8	62.3	60.2	60.1	62.0	62.7	55.1	64.4	60.8
ML107455	56.3	62.0	57.7	55.0	58.6	57.5	58.1	59.0	60.3	61.7	58.3	59.6	61.0	61.0	54.3	61.7	59.1
OR870453	56.3	61.0	57.8	56.6	57.8	57.9	59.5	59.3	59.0	59.7	57.3	57.4	59.6	59.9	56.2	61.6	58.0
NURSERY MEAN	57.5	61.1	58.2	55.9	58.2	58.5	59.8	59.5	59.7	60.2	58.5	58.7	59.8	60.2	55.8	62.2	59.2
CV %	1.9	2.2	2.3	3.7	1.5	2.3	9.3	1.5	1.1	1.4	3.0	1.6	1.3	0.8	-	1.1	1.9
LSD @ .10	1.3	1.5	1.6	2.5	1.0	1.6	0.7	1.1	0.7	1.0	2.0	1.1	0.9	0.6	-	0.8	0.5

Analysis Method - General Linear Models Proceedure

1998 WSU SPRING WHEAT VARIETY TRIAL SUMMARY
PROTEIN (%)

VARIETY NAME	BICKLETON	HORSE HEAVEN	LIND ANNUAL	POMEROY	DAYTON	LIND FALLOW	RITZVILLE	LAMONT	REARDAN	FAIRFIELD	DUSTY	ST. JOHN	FARMINGTON	PULLMAN	MOSES LAKE	ROYAL SLOPE	VARIETY MEAN
Soft White Common																	
ALPOWA	11.2	10.1	13.1	11.5	9.8	11.8	8.5	9.4	9.8	9.2	10.6	9.3	8.3	8.9	13.0	10.8	10.2
BZ 692-108	10.9	10.4	11.5	12.1	10.3	11.4	8.8	9.1	9.5	9.9	11.1	10.1	8.4	9.8	12.7	10.6	10.3
EDWALL	11.6	10.4	10.7	12.1	10.0	11.8	9.4	9.7	10.4	9.6	10.7	9.1	8.7	10.6	12.8	10.8	10.4
FIELDER	11.6	10.6	12.2	12.0	10.0	11.7	8.8	9.2	9.4	10.4	11.9	9.7	8.7	10.6	11.7	10.4	10.5
ID505	11.2	10.4	11.6	10.5	10.9	11.5	8.9	9.8	8.8	9.3	11.0	9.9	8.6	9.5	12.7	10.2	10.2
ID506	11.9	10.9	12.2	12.5	11.3	12.7	9.4	9.9	9.7	10.4	11.4	11.5	8.8	10.4	12.7	10.8	11.0
ML409015	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	10.9	10.9
PENAWAWA	11.1	9.4	12.1	12.8	10.0	11.4	8.7	10.0	9.4	10.1	11.5	10.1	8.3	9.9	13.2	10.2	10.4
POMERELLE	12.3	9.9	12.2	13.4	10.8	12.5	8.9	9.7	10.5	10.5	10.9	10.0	8.4	9.9	13.3	10.3	10.7
VANNA	11.1	9.9	12.6	12.1	10.3	11.8	8.5	9.0	9.5	9.3	10.4	9.5	8.7	10.1	13.4	10.3	10.3
WA7850	11.8	10.6	12.8	12.7	10.9	13.0	9.7	9.9	10.2	10.3	11.7	10.7	8.8	9.9	13.6	11.0	11.0
WA7851	11.3	11.4	12.3	13.5	12.0	12.5	9.8	10.3	9.7	9.7	11.6	10.0	8.8	9.9	13.2	10.9	11.0
WA7862	11.6	10.2	11.7	12.2	10.4	12.4	9.2	9.8	11.1	10.6	12.1	10.4	9.6	10.3	14.0	10.7	10.9
WA7864	12.0	10.9	11.9	12.4	11.1	11.8	9.5	10.3	10.2	10.1	12.6	9.7	9.0	10.5	13.5	11.1	10.9
WAKANZ	11.7	10.2	12.5	11.6	10.8	12.4	9.4	10.3	10.4	10.1	11.3	10.7	9.6	9.7	13.0	11.4	10.9
WAWAWAI	11.6	10.8	11.9	12.5	10.3	12.5	9.6	10.6	10.3	10.2	11.3	10.7	9.1	10.7	13.7	11.3	11.0
WHITEBIRD	11.2	10.6	12.3	12.8	11.1	11.9	9.2	10.6	10.1	10.1	11.5	10.4	9.1	10.2	12.1	10.5	10.8
Soft White Club																	
CALORWA	11.9	11.6	11.8	12.9	10.8	12.5	9.8	9.5	10.1	10.1	11.8	10.9	9.4	11.0	13.1	10.9	11.0
Hard Red Common																	
BUTTE 86	12.6	13.5	13.0	13.1	12.4	13.0	10.7	10.9	11.8	12.2	13.0	12.0	11.5	12.0	15.4	14.2	12.5
EXPRESS	12.8	12.7	13.4	13.1	12.0	12.8	10.0	10.1	10.9	11.3	11.1	10.5	9.8	10.8	15.1	13.6	11.7
JEFFERSON	13.4	11.3	12.5	12.1	11.2	12.2	9.4	10.2	11.6	11.4	11.7	11.1	10.7	10.9	14.5	13.0	11.6
KULM	12.9	13.6	14.0	13.4	13.2	13.6	11.3	12.5	12.6	13.7	14.5	12.0	12.4	12.3	16.7	14.9	13.2
NW#10	13.1	12.3	13.0	13.9	12.0	12.6	10.4	11.0	11.9	12.1	13.1	10.5	10.8	11.4	16.4	13.0	12.2
SCARLET (WA7802)	13.0	12.0	12.3	13.7	11.9	12.6	10.4	11.8	11.0	11.8	12.5	11.8	10.8	11.4	15.5	12.5	12.0
SPILLMAN	13.1	12.2	12.8	13.9	12.2	12.9	10.3	10.1	11.1	12.0	11.4	11.0	10.4	11.6	15.3	12.8	11.9
WA7824	12.5	14.0	12.0	13.5	12.3	12.6	10.4	11.3	11.4	11.1	12.4	11.5	10.0	11.7	14.2	13.3	12.1
WA7839	11.7	13.5	13.2	12.9	11.4	12.5	10.2	10.1	10.9	11.4	11.3	10.6	10.0	11.4	14.9	13.1	11.7
WA7840	13.4	13.1	13.1	14.5	11.9	13.2	10.6	11.1	11.8	12.3	12.0	12.7	11.3	11.9	16.3	13.0	12.5
WA7841	13.1	13.3	12.9	14.9	12.2	13.9	10.7	11.4	11.6	12.2	12.2	12.6	11.1	12.2	16.1	13.7	12.6
WA7842	13.4	12.6	12.6	13.8	11.6	13.2	10.5	11.7	12.4	12.3	13.3	11.8	11.6	11.7	16.3	13.6	12.5
WA7845	12.6	11.9	12.4	14.1	11.5	12.7	10.1	10.9	11.6	12.9	12.2	12.3	10.8	11.9	16.7	13.5	12.2
WA7858	12.1	12.3	13.5	12.6	12.6	12.8	10.3	9.9	11.8	11.9	11.9	9.7	10.3	11.8	16.2	13.7	11.9
WPB 926	13.3	13.2	13.9	14.1	11.7	13.0	10.6	10.9	11.9	12.5	12.2	11.3	11.0	11.6	16.0	14.1	12.4
WPB 936	12.8	13.3	12.5	13.9	11.1	12.6	10.0	9.4	10.9	10.4	11.4	9.9	10.1	10.3	15.5	12.5	11.5
WPB87331	12.2	13.0	13.1	12.0	10.7	12.3	10.0	10.0	10.0	10.4	11.2	9.4	8.9	10.2	15.0	12.8	11.2
Spring Durum																	
KRONOS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	14.1	14.1
NPB871104E	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	13.6	13.6
Hard White Common																	
ID377S	12.6	11.4	12.0	13.0	9.8	12.3	9.3	10.7	11.2	11.0	13.1	11.2	9.2	10.4	14.2	12.0	11.3
ID523	13.5	10.8	12.3	12.3	10.9	11.0	9.7	10.6	10.6	11.0	12.7	11.3	9.8	10.0	14.2	11.4	11.3
ID533	12.6	11.0	12.0	13.6	10.8	11.7	9.7	11.0	10.4	11.2	11.9	11.4	10.0	10.4	13.7	12.2	11.4
ML107455	13.1	11.8	12.6	12.5	11.3	12.1	10.1	10.4	11.4	10.9	11.4	10.0	9.9	10.2	14.0	11.7	11.4
OR870453	13.2	11.2	12.0	11.5	10.6	11.6	9.6	10.4	10.7	10.7	11.3	10.6	9.5	9.8	13.7	11.3	11.0
NURSERY MEAN	12.3	11.6	12.5	12.9	11.2	12.4	9.8	10.4	10.7	11.0	11.8	10.7	9.8	10.7	14.3	12.1	11.4
CV %	6.3	7.9	7.9	9.9	9.0	7.1	5.0	8.4	7.1	8.2	6.0	5.6	8.6	2.8	-	4.5	7.2
LSD @ .10	0.9	1.1	1.2	1.5	1.2	1.0	0.6	1.0	0.8	1.0	0.8	0.7	1.0	0.3	-	0.6	0.3

Analysis Method - General Linear Models Proceedure

Barley Improvement Research

S.E. Ullrich, V.A. Jitkov, J.A. Clancy, J.S. Cochran, and M.J. Young

Collaborators: A. Kleinhofs, D. von Wettstein, J.M. Zale, W. Gao, E. Donaldson†
S.M. Dofing, P.E. Reisenauer, J.A. Froseth, R.J. Cook, and R.L. Line

Cultivar Development/Variety Testing

The overall goal of the WSU Barley Improvement Program is to make barley a more profitable or valuable crop. Specific objectives are to improve agronomic and grain quality factors and pest (disease and insect) resistance for dryland and irrigated production. The emphasis is on two-row spring barley with additional efforts on six-row spring, spring hulless &/or waxy, and winter types.

The latest releases from the Barley Improvement Program were two new spring barley cultivars in 1997; 'Bear', a two-row hulless type and 'Washford,' a six-row hooded (beardless) hay type. A spring two-row line, WA9504-94, was approved in February 1999 for preliminary seed increase with a probable decision for release in February 2000.

Bear -- A New Two-Row Spring Hulless Barley. Bear yields well relative to other hulless cultivars in eastern Washington and northern and southern Idaho. The test weight of Bear has ranged from 57 to 60 lb/bu. Nutritional quality of Bear is very good based on starter pig, mobile nylon bag technique, and *in vitro* trials. It is expected to be used for livestock feed and potentially for human food.

Washford – A New Six-Row Spring Forage (hooded) Barley. Harvested at the grain soft-dough stage, Washford produced 15%) more hay and 22% more seed than the old standard, Belford . Washford is shorter than Belford by 8% and has greater lodging resistance. All agronomic data are averages over 6 years of tests at Pullman. Washford had the highest hay yield at four of the eight 1996 Montana/Wyoming locations and was equal to the highest yielder at two additional locations. Few disease symptoms have been noted on the forage barleys. However, Washford has shown some susceptibility to loose smut caused by *Ustilago nuda*. There is limited quality data, but appears to be comparable to Belford in feed value. Washford is expected to be used primarily for hay, but also other forage uses for ruminant livestock. It should supplant Belford.

WA9504-94 – A New Two-row Spring Feed/Malting Barley. This semi-dwarf line has shown wide adaptation in eastern Washington, high malting quality, and a moderate level of resistance to barley stripe rust (BSR). It is expected to compete better in eastern Washington than other BSR resistant cultivars recently released compared to the high yielding BSR susceptible feed cultivars such as Baronesse.

For spring barley in 1998, 131 crosses were made. In 1999, plants will be selected from 175 segregating F_3 populations (50-100/population). In addition, there are 104 F_2 single seed descent populations in the greenhouse. Lines will be selected from approximately 10,000 head and rows.

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† Deceased. Acknowledgement and appreciation is expressed for all Ed did for the Variety Testing Program.

There are approximately 1,000 single replication evaluation plots planted at Spillman Farm and Ritzville or Royal Slope this year; the entries of which mostly came from 1998 head/plant rows. The more advanced lines are tested in 20 30- to 48-entry major yield trials at Spillman Farm and throughout eastern Washington including a 48 entry preliminary state yield trial at three locations – Pullman, Fairfield, and Ritzville – and the state uniform trial of 39 entries planted at 14 locations (seven extension/Dofing and Reisenauer). There were 11 grower-conducted on-farm tests with seven entries in seven counties in 1998 coordinated by Kevin Anderson of Great Western Malting Company and Roland Schirman and other area/county extension agents in eastern Washington.

Barley performance in 1998 was presented in the Nov. 6, 1998 *Green Sheet* and in the Jan. 1999 *Wheat Life*.

Grain quality evaluations of breeding lines and cultivars are conducted on field-grown samples. Basic kernel quality characteristics, such as test weight and kernel plump-thin percentages, are measured in our laboratory. Malting quality is evaluated at the USDA-ARS Cereal Crops Research Unit at Madison, Wisconsin. Feed quality evaluations have been conducted in the Department of Animal Sciences primarily by John Froseth.

Pest Resistance. While yield and grain quality are always important selection criteria, pest resistance is moving up in priority. Crossing, screening and selection for Russian wheat aphid, barley stripe rust and soil borne pathogen resistance is underway. The Russia wheat aphid is a relatively new pest in the Pacific Northwest (PNW) and has the potential to inflict serious damage to the barley crop. Reaction screening is carried out at the USDA-ARS Insect Laboratory at Stillwater, Oklahoma. RWA resistant lines were grown in field tests in 1998. Barley stripe rust (BSR) is a new disease to the PNW and little resistance exists in currently grown barley cultivars. Rollie Line is collaborating on monitoring and testing for this disease. We have had germplasm screened for barley strip rust reaction the past several years in Bolivia, Texas, Colorado, and Washington. Expanded field testing of resistant lives began in 1997. There appears to be good resistance in a number of WSU breeding lines including WA9504-94 described above. Soil borne pathogens probably affect barley production more than we realize. A new effort was initiation in 1994 through Vadim Jitkov's M.S. research project in collaboration with Jim Cook to screen for reaction to soil borne pathogens in the field and growth chamber. Barley cultivars and breeding lines have been identified with resistance to *Rhizoctonia solani* for the first time. Relatively simple inheritance of resistance is indicated which should facilitate breeding for resistance to this soil borne pathogen. Field testing for soil borne pathogen reaction has been expanding over the past few years with nurseries planted at Spillman Farm, Dusty, Ritzville, and Bickelton in 1998. Tests at these cites are repeated in 1999. Backcross breeding projects are underway for Russian wheat aphid, barley stripe rust, and *Rhizoctonia* resistance.

Application of Biotechnology

Collaboration in the North American Barley Genome Mapping Project involves work on several fronts with Andy Kleinhofs, Janet Clancy, Janice Zale, and Wenxiang Gao. The first comprehensive map developed from Steptoe/Morex is being applied to quantitative trait locus (QTL) analysis and molecular marker assisted selection relevant to cultivar development. We are verifying QTL identified and developing molecular marker assisted selection strategies for use in the breeding program. Initially, we are concentrating on the dormancy trait and yield from

Steptoe, several malting quality traits from Morex, *Rhizoctonia* resistance from identified germplasm sources, and barley stripe rust resistance from several sources. Mapping populations from the Harrington/TR306 and Harrington/Morex crosses are also being evaluated. The incorporation of yield QTL from Baronesse and barley stripe rust QTL from Orca into Harrington and the incorporation of Steptoe yield QTL into Morex are collaborative projects with Andy Kleinhofs, Dave Kudrna, and Nejdet Kandemir. The availability of a detailed genome map allows us to begin to understand the genetics of complex economically important agronomic (yield, lodging, maturity) and quality (feed, kernel, malting) traits through QTL analysis. With the identification and location of specific genes, marker-assisted selection strategies can be developed for more directed breeding.

Collaboration in breeding proanthocyanidin-free barley and transformation of barley with a heat-stable beta-glucanase (brewing and feed quality traits) is underway with Diter von Wettstein and Judy Cochran. The transformation project will see transformed plants in the field for the fourth year in 1999. The proanthocyanidin-free barley project has been a long-time collaboration. A boost to the project occurred with the induction and incorporation of pigmented "pant" mutants (vs anthocyaninin-free types), which have improved adapted and higher quality.

1998 Variety Testing Program - Spring Barley

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Overview

The 1998 state spring trial consisted of 43 entries grown at 13 locations. Trials at Fairfield, Pullman, Pomeroy, Ritzville, Lind, and Royal Slope were grown cooperatively with the spring barley breeding program. The trial at Royal Slope was irrigated, and the remaining trials were dryland.

Nine entries were 6-row, and 32 were 2-row. Two hulless varieties, Bear and Condor, were also included. Four entries, 96529, Akcent, HE6291, and HE6890 were included only in the irrigated trial at Royal Slope.

Growing Conditions

1998 growing conditions were generally excellent for barley production. Moisture was adequate throughout the growing season, and temperatures were above average. Dry conditions during harvest were conducive to timely harvest.

Results

Across all locations, WA10178-93 was the highest yielding 6-row variety, followed by Tango. Morex has not demonstrated superior adaptation in Washington. Among 2-row varieties grown at all locations, Baronesse was again the highest yielder. It was also the highest yielding variety among all entries in the trial. The second highest yielding entry was Xena, with a yield slightly below Baronesse. The next highest yielding named variety was Riviera, yielding considerably below Xena.

Test weights were generally high in 1998, with an overall average of 50 lbs/bu. Test weight of Steptoe was only 45.9 lbs/bu.

Acknowledgments

This work was made possible by funding provided by the Washington Barley Commission, WSU College of Agriculture and Home Economics, Washington State Crop Improvement Association, fees paid by private companies, and the generous contribution of cooperators who provided land and other assistance required to grow these trials.

1998 WSU SPRING BARLEY SUMMARY
YIELD (LBS/A)

VARIETY NAME	BICKLETON	LIND FALLOW	LAMONT	POMEROY	RITZVILLE	REARDAN	FAIRFIELD	PULLMAN	DAYTON	DUSTY	ST. JOHN	FARMINGTON	ROYAL SLOPE	VARIETY MEAN
6-row														
MOREX	1790	2642	3149	2940	3875	3747	3271	2202	3040	3765	4289	3983	4480	3321
STEPTOE	2213	3415	3863	3393	4195	4339	3794	2771	4080	4581	4672	4910	5382	3970
TANGO	2416	3281	3614	3311	3636	4648	4294	4445	4286	4689	5053	5046	5338	4158
WA 10178-93	2148	3079	3604	3514	4135	4463	4468	4370	4457	4287	5177	5127	5353	4168
WA 10494-93	2130	3048	3435	3666	4056	4376	3891	4315	4392	4287	5117	5505	5614	4141
WA 18009-94	2014	3066	3113	3691	3745	4492	4412	3255	4332	4104	5034	5062	5551	3990
WA 18060-94	1920	3160	3063	3694	3890	4065	4657	4052	4386	4271	4794	5026	5405	4029
WA 21832-94	1985	3232	3349	3571	3640	4525	4259	3486	3932	4164	5230	5078	4718	3936
WA 22384-94	2009	4002	3080	3914	3300	3947	3595	2439	4777	4151	5252	4872	4955	3869
2-row														
96529	.	.	.	.	.	.	.	.	.	.	.	.	5875	5875
AKCENT	.	.	.	.	.	.	.	.	.	.	.	.	6093	6093
ANT-2110	1947	3018	3401	3530	4038	4684	4510	4844	4419	4859	5039	5822	5082	4246
BANCROFT	2135	2883	3699	3512	4067	4378	4030	3914	4452	4524	5073	4739	4880	4022
BARONESSE	2759	3519	4481	3841	4392	4870	5104	4955	4994	5200	5888	5307	5743	4696
BZ 594-19	2494	3626	3806	4246	4508	5088	4641	5009	4507	4967	5789	5839	6284	4677
CA 108702	2120	3082	2993	3637	4162	4159	4837	5315	4552	4182	5039	5453	6305	4295
CA 803111	2560	3398	3185	3753	4074	4800	4225	4954	4593	4283	4784	5477	5241	4256
CA 803803	2518	3179	3239	3873	4234	4310	4233	5712	4502	4217	5342	5617	6271	4404
CAMELOT	2155	3328	3474	4037	3969	4050	4161	4562	4609	4463	5280	4928	4693	4131
CAMINANT	1799	3147	3032	3658	3836	4274	4769	5296	4214	4319	4739	5606	5764	4189
CREST	2336	3204	3489	3592	4142	4319	4370	4052	4479	4530	5258	4818	5503	4161
CSBA 4315-110	2554	3586	3237	4063	4088	4650	4903	5098	4782	4494	5596	5637	5831	4501
GALLATIN	2168	2970	3625	3448	3899	4141	4089	4210	4200	4548	4962	4675	5427	4028
HARRINGTON	2317	2919	3448	3511	3955	4211	4423	3436	4507	4698	5211	4350	5677	4051
HE6291	.	.	.	.	.	.	.	.	.	.	.	.	6693	6693
HE6890	.	.	.	.	.	.	.	.	.	.	.	.	6000	6000
MELTAN	2341	3387	3468	4030	4205	4347	4767	5373	4896	4844	5246	5396	5499	4446
ORCA	2041	2734	3938	3591	3306	3975	4001	4857	4496	4917	4708	5141	6238	4149
RIVIERA	2245	3413	3639	3908	3761	4547	5216	5371	4758	4761	5438	5811	6220	4545
SG 188	2478	3306	3287	4126	4321	4449	5002	5438	4946	4772	5244	5792	6264	4571
SG 522	2276	3333	3431	4126	4195	4898	4581	4407	4630	4712	5384	5435	5735	4396
STRATUS (TR-128)	2469	3062	3444	3742	4093	4399	4437	4796	4474	4714	4842	4796	6546	4293
WA 10552-94	2276	3480	3218	3832	3748	4308	4141	3743	4874	4684	5124	4907	5660	4153
WA 10576-94	2291	3678	3291	3724	3925	4783	4307	3966	4520	4539	5333	5517	5991	4297
WA 7114-93	1985	3380	3675	3400	3962	4370	3620	4173	4433	4290	5066	4703	5280	4026
WA 7642-92	2164	3443	3512	3752	4070	4650	4705	4809	4650	4496	5224	5475	5700	4358
WA 8394-93	2070	3359	3450	3796	4249	4258	4618	3393	4436	4798	5228	5339	5559	4196
WA 8772-93	2211	3191	3664	3602	4242	4556	4991	5305	4608	4415	5247	5319	5618	4382
WA 9283-94	2074	3181	3361	3847	3978	4134	4307	4506	4520	4676	5035	4759	5307	4130
WA 9504-94	2347	3281	3328	3839	3933	4505	5182	5238	4386	4471	5174	6129	5998	4447
WA 9508-94	2218	3329	3453	3539	4005	4169	4621	4551	4465	4337	5425	4821	6153	4237
Hulless														
BEAR	1553	1862	3879	2899	3422	2906	3091	3383	3238	3711	4175	4272	4715	3316
CONDOR	1947	2778	2898	3165	3571	3712	3281	3973	3798	4054	4631	4498	5076	3645
NURSERY MEAN	2192	3205	3444	3675	3970	4346	4354	4358	4426	4481	5106	5153	5621	4191
CV %	18.3	11.6	16.0	7.5	6.1	5.4	12.1	9.2	9.4	11.6	6.3	7.4	12.5	10.4
LSD @ .10	471	438	644	322	284	277	617	468	488	610	374	449	823	204

Analysis Method - General Linear Models Proceedure

1998 WSU SPRING BARLEY SUMMARY
TEST WEIGHT (LBS/BU)

VARIETY NAME	BICKLETON	LIND FALLOW	LAMONT	POMEROY	RITZVILLE	REARDAN	FAIRFIELD	PULLMAN	DAYTON	DUSTY	ST. JOHN	FARMINGTON	ROYAL SLOPE	VARIETY MEAN
6-row														
MOREX	48.5	49.5	49.2	47.3	49.3	49.7	48.0	41.9	50.1	50.3	49.9	48.3	48.0	48.5
STEPTOE	47.0	45.8	46.1	46.0	44.5	47.2	45.1	41.4	48.5	44.9	47.4	46.4	45.8	45.9
TANGO	47.3	47.7	48.0	48.2	46.5	49.0	47.9	45.8	49.5	47.1	48.7	47.3	44.9	47.5
WA 10178-93	46.4	48.4	47.1	45.9	47.4	48.9	48.3	45.6	49.8	47.7	48.6	48.7	46.2	47.6
WA 10494-93	49.3	50.7	49.5	47.8	50.9	51.2	50.9	47.6	51.2	51.0	50.2	50.3	50.1	50.1
WA 18009-94	46.2	46.0	45.4	43.1	44.8	48.0	45.0	39.7	48.4	46.3	46.4	45.5	44.5	45.4
WA 18060-94	45.1	46.7	46.1	44.9	45.9	46.9	46.4	43.5	48.3	46.4	47.2	46.9	44.2	46.0
WA 21832-94	48.1	47.7	48.0	46.0	46.2	49.8	48.3	44.5	47.2	45.7	48.9	48.6	46.7	47.4
WA 22384-94	47.4	49.7	47.1	43.2	46.3	47.7	42.1	37.7	49.6	45.8	48.6	46.0	41.0	45.6
2-row														
96529	.	.	.	.	.	.	.	.	.	.	.	.	51.5	51.5
AKCENT	.	.	.	.	.	.	.	.	.	.	.	.	51.2	51.2
ANT-2110	49.5	49.0	49.8	45.1	49.4	51.5	49.4	45.9	48.6	47.1	49.5	49.8	48.3	48.7
BANCROFT	49.7	49.7	49.9	49.6	50.8	52.3	50.9	48.1	52.9	49.1	52.5	49.6	49.2	50.3
BARONESSE	49.6	49.9	51.1	49.4	51.2	52.9	51.7	48.0	52.3	50.0	51.5	48.5	51.6	50.6
BZ 594-19	49.2	50.9	50.4	50.3	51.2	52.5	52.8	48.2	52.2	49.8	52.7	51.2	50.0	50.9
CA 108702	49.2	49.8	49.7	48.8	50.7	51.4	50.4	47.6	51.6	48.2	50.9	50.1	51.6	50.0
CA 803111	50.5	50.8	49.0	48.9	49.7	52.1	50.6	47.0	51.1	48.4	50.3	49.8	51.7	50.0
CA 803803	49.8	51.0	49.5	48.8	50.4	52.1	52.1	49.0	51.5	49.3	51.1	51.8	52.1	50.7
CAMELOT	50.5	52.3	50.7	52.1	52.3	53.2	53.5	49.3	53.4	52.3	52.8	51.5	51.7	52.0
CAMINANT	49.0	51.4	49.0	49.2	49.9	51.5	51.3	47.4	50.8	48.3	50.4	50.7	50.8	50.0
CREST	51.1	51.4	51.4	51.5	52.1	53.0	52.5	48.3	53.9	50.6	53.3	50.5	51.7	51.7
CSBA 4315-110	50.4	50.8	49.2	49.0	51.7	51.5	52.0	48.1	52.5	50.9	51.2	51.0	51.2	50.7
GALLATIN	50.5	51.8	52.0	52.4	53.5	53.9	52.8	49.9	53.4	51.7	53.3	50.9	53.2	52.3
HARRINGTON	50.3	47.9	49.2	46.6	50.5	52.5	50.6	44.9	51.0	48.1	50.7	48.4	47.2	49.1
HE6291	.	.	.	.	.	.	.	.	.	.	.	.	51.4	51.4
HE6890	.	.	.	.	.	.	.	.	.	.	.	.	51.6	51.6
MELTAN	50.8	51.7	50.8	50.6	51.9	52.8	52.5	49.5	52.4	50.4	52.3	52.1	51.8	51.5
ORCA	51.1	52.6	51.8	50.8	51.3	51.9	51.4	51.8	53.7	51.8	52.2	50.9	50.8	51.7
RIVIERA	48.3	50.6	48.0	48.3	50.2	50.7	51.8	48.6	50.7	49.8	50.4	49.9	51.8	49.9
SG 188	51.3	52.4	50.7	51.0	52.0	52.3	52.6	50.6	53.4	52.5	52.9	52.6	52.1	52.0
SG 522	48.7	48.9	49.3	49.0	51.1	52.6	50.6	46.9	51.2	49.1	51.0	49.4	49.9	49.8
STRATUS (TR-128)	49.6	51.4	49.8	50.8	51.2	51.7	52.0	49.7	52.3	51.7	52.9	50.2	51.9	51.2
WA 10552-94	49.3	49.2	48.4	47.2	48.1	50.2	47.3	43.2	50.4	48.5	50.3	48.4	47.7	48.3
WA 10576-94	49.9	50.4	49.2	47.6	48.5	51.2	47.7	41.3	51.1	49.7	50.1	49.7	52.1	49.1
WA 7114-93	47.2	47.9	48.0	45.1	49.6	51.3	48.1	44.3	48.8	46.7	48.9	47.4	48.5	47.8
WA 7642-92	50.0	50.2	50.5	49.6	51.3	53.0	52.0	47.5	53.0	48.5	52.2	49.9	48.8	50.5
WA 8394-93	48.0	48.8	49.3	47.7	49.2	51.4	49.8	42.5	50.3	46.2	49.6	48.9	48.5	48.5
WA 8772-93	50.0	51.2	51.0	51.4	52.4	53.0	52.9	50.9	52.9	50.9	52.4	52.3	52.3	51.8
WA 9283-94	48.7	50.3	49.7	50.6	51.7	52.1	50.4	46.7	51.4	48.5	51.9	51.2	49.7	50.3
WA 9504-94	49.7	50.9	49.9	49.6	50.8	51.9	52.1	48.6	52.2	49.3	50.7	51.8	51.9	50.7
WA 9508-94	49.9	49.6	49.8	49.1	51.3	51.9	51.8	47.0	52.1	50.6	52.0	49.3	51.6	50.5
Hulless														
BEAR	53.9	58.0	57.1	55.5	55.2	59.6	54.3	51.8	60.2	58.4	60.4	56.6	56.3	56.7
CONDOR	56.0	58.6	59.0	57.5	57.1	60.2	59.5	54.0	59.6	59.0	60.7	57.7	60.5	58.4
NURSERY MEAN	49.4	50.3	49.8	48.9	50.2	51.7	50.5	46.8	51.6	49.5	51.2	50.0	50.1	50.0
CV %	2.1	3.0	1.9	3.0	1.3	0.8	2.6	2.1	1.7	2.7	2.1	1.9	2.5	2.2
LSD @ .10	1.2	1.8	1.1	1.7	0.7	0.5	1.5	1.2	1.0	1.5	1.3	1.1	1.4	0.5

Analysis Method - General Linear Models Proceedure

New Directions of the Grain Legume Breeding Program

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The grain legume breeding program is focussed on producing new improved cultivars of dry pea, lentil, chickpea and Austrian winter pea. Industry is demanding a wide range of types within each crop. These types must be environmentally adapted, high yielding, and market acceptable. Meeting these demands has necessitated accelerating the breeding process. An increased use of greenhouse screening techniques for early generation breeding material coupled with intense field screening of selected material has resulted in dramatically reducing the overall time from initial parental selection and cross pollinations through to cultivar release. The breeding efforts directed at each of these crops are described below.

Dry peas:

Dry peas are an important rotational crop to the cereals in the Palouse region of eastern Washington and northern Idaho. The crop provides an alternative to the cereal grains and is considered necessary in order to break disease cycles, improve weed control and fertility status of the soils. The crop is attacked by a number of diseases of which root rots, wilts, viruses and powdery mildew can be of epidemic proportions. Currently, the dry pea crop is made up of 80% smooth, round-seeded green types (typical of "Alaska" peas). The remainder is made up of smaller-seeded green types ("small sieves") and large yellow-seeded types. The principal quality factor for the smooth green types is good color retention and resistance to seed bleaching. Cultivars are needed which will retain their dark green cotyledon color even though moist conditions known to be conducive to seed bleaching may occur. Progress has been made under previous industry supported projects in the development of dry pea lines with multiple disease resistance, particularly to root rot, wilt, powdery mildew and viruses (mainly bean leaf roll and pea enation mosaic).

Progress is also being made in developing lines with greater resistance to seed bleaching and with darker seed coats. The method currently in use in the greenhouse and laboratory to identify good color qualities of the seed coats and cotyledons is working exceptionally well. Selections made using those techniques have shown marked improvement in color qualities. Those lines, and additional lines to be identified using that screening procedure, will provide the industry the quality and disease resistance needed to remain competitive in world markets.

A recent trade mission trip to China revealed that the market for marrowfat type peas is growing and could play an important role in the Pacific Northwest. Marrowfat peas are green in color and approximately twice the size of the traditional smooth green peas (35-40 vs. 18-22 gm/100 seed). They are oblong and have an irregular or dimpled seed surface. They are used in soups in the United Kingdom and in China they are used in the snack food industry. Snack processing includes soaking the seed and frying it in hot vegetable oil until crunchy and then adding seasonings to the seed surface for flavor. Market requirements include extremely large seed size, dark green color (<30% bleach) and excellent seed coat integrity.

The dry pea breeding program has recently been expanded to include the orange cotyledon types. This type is not grown extensively at this time, but has great potential in the marketplace as an ingredient in soup mixes much like the 'Redchief' lentil. The first crosses were made in the fall of 1998 and segregating populations are in the field for evaluation for the first time this year.

In 1997, three new cultivars were released, 'Shawnee', 'Fallon' and 'Joel'. Shawnee is a long-vined type with yellow cotyledons and a normal leaf type. It was released as a replacement for 'Umatilla'. Fallon is a semi-dwarf type with yellow cotyledons and the semi-leafless or afila leaf trait. Although it does not remain completely upright at maturity, it has a more upright growth habit than the other long-vined cultivars. Joel was released as a replacement for 'Columbian', but has not been readily accepted by the industry as yet.

Future objectives of the dry pea breeding program include continued increases in yield potential, bleach resistance, upright growth habit and multiple disease resistance. Development of an orange-seeded pea that is adapted to the Pacific Northwest and a marrowfat cultivar suited to the snack food industry are currently a major focus of the program. Over the past four to five years the afila leaf trait has been incorporated into many of the breeding lines to confer an upright growth habit conducive to direct harvesting with a wheat header. Several lines are currently in the advanced yield trials at four locations and are being considered for release.

Lentils:

The lentil industry of the U.S. competes in the world market and must have cultivars that produce acceptable quality of the various market classes. For that reason, cultivars with improved yields and seed quality are essential to maintaining and improving competitiveness. Until very recently, the Palouse region produced only one type of lentil, the so-called Chilean type ('Brewer') with large, yellow cotyledons. Indications now are that several types can be produced and sold in various markets both domestically and worldwide. An exceptionally large yellow-seeded lentil with uniformly green seed coats is needed by the industry to compete in markets in the Mediterranean region. In addition to a large yellow lentil cultivar, the industry would benefit from a small Turkish red type of lentil.

Crimson was released in 1990 as a Turkish red type. 'Mason' a large yellow cotyledon type was released in 1997 and has exceptionally large seed size and is higher yielding that Brewer. It also produces large amounts of residue that is beneficial for soil conservation. Additional work toward an 8-9 mm diameter lentil is underway. Improved selections are being tested in 1999 and one or more will be proposed for release to the industry this fall. The improved selection will have better standing ability, higher yields and increased amounts of residues.

Chickpea (Garbanzo beans):

Ascochyta blight is a devastating disease of chickpea in the Palouse area and has caused serious problems with the production of the crop. Success in the early 1990s led to the development of cultivars such as 'Dwelley' and 'Sanford' made it possible to grow the crop with some assurance that the disease will not be so devastating. In 1997, 'Evans' was also released as an earlier flowering and maturing variety with resistance to Ascochyta blight. These three cultivars are the only large-seeded kabuli types with resistance to Ascochyta blight available for production. Recent market information indicates that there is an increasing demand for the so-called 'Spanish White' type which is characterized by exceptionally large white seeds. Numerous crosses were made to incorporate Ascochyta blight resistance into the Spanish White type. During the 1998-99 winter season, lines of the Spanish White type were winter increased at Yuma, Arizona to provide additional seed for yield testing and also to gain a year in development time. A decision will be made on one or more of the lined for release after this year of yield and quality testing.

In addition to the work on the Spanish White type, there is a need to improve on the resistance to blight in Sanford and Dwelley. Those cultivars need to have better resistance to the pod infection phase of the disease. Germplasm has been identified in the blight screening nursery with good resistance to pod infection. Resistance to pod infection in the regular cream colored cultivars and a blight resistant Spanish White cultivar are needed for future long-term control of the disease. Also, we are working on a 'Café' type of chickpea that should be available for release at the same time as the new Spanish White variety.

Approximately fifty Spanish White type breeding lines with large white seeds were increased in Yuma, Arizona last winter. The lines with the best seed size and color have been planted at Walla Walla and Pullman, Washington and at Genesee, Idaho. The two highest yielding lines with resistance to Ascochyta blight will be considered for release. One line will have the fern leaf type and the other will have the simple leaf type.

Winter Peas:

Two types of winter peas are currently being developed. The first is the Austrian winter pea and the second is a white-flowered, clear-seeded pea that is edible and is similar to the Alaska type. The Austrian winter peas are an alternative legume crop on the Camas Prairie of northern Idaho and to a limited extent in southeastern Washington and eastern Oregon. The crop is important in these areas as an alternative to the cereals, fits well in to the rotation and can be planted in the fall. Fall planting is important because wet soil conditions often make it difficult to plant in the spring. In the past, Austrian winter peas have been exported to the Orient where they are used as filler in the production of An-paste, a confection made mostly from the expensive Azuki beans. Other uses include a green manure crop in the southeastern U.S., inexpensive split yellow peas and bird seed.

Production of the crop has declined over the past 10 years due to a serious problem with Aphanomyces root rot and infestations of Ascochyta blight and Sclerotinia white mold. These foliar disease problems appear to be solvable through the use of plant types that keep the canopy upright during most of the growing season increasing air movement thereby reducing the humidity in the lower canopy. The root disease problem is somewhat more difficult. However, we have established root disease screening nurseries that have the potential of identifying genetic material with tolerance to the most important root rotting pathogens. The development of multiple disease resistant varieties is needed if this crop is to continue as an integral part of the cropping system used in the Camas prairie. The most urgent need is to develop cultivars with resistance to these diseases and with sufficient winterhardiness to be grown over a wide area.

'Granger' is the most recently released Austrian winter pea cultivar. It has been widely accepted by the industry and has been grown on a large number of acres in northern Idaho. Granger is long-vined and has the semi-leafless trait allowing it to stand more upright and reduce the severity of foliar disease during the season.
In 1998, the trial at Spillman Farm was severely infected with pea enation mosaic virus and Ascochyta blight which provided an opportunity to eliminate many lines that were susceptible. Many crosses have made to introduce resistance to these diseases into the most winterhardy lines.

Winter lentil:

A breeding program for winter lentil has been established and many breeding lines have been identified with excellent winter hardiness. Three main types of winter lentil are being developed, large red, large yellow and small yellow cotyledon types. To date it has been difficult to combine high yield and winter hardiness into the large-seeded types. Several winter lentil selections are currently being tested in direct seed systems.

Wheat and Barley Root Disease Research

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Our research is focused on three major root diseases of wheat and barley. These are: Take-all caused by *Gaeumannomyces graminis*, var. *tritici*; Pythium root rot, caused by several *Pythium* species; and Rhizoctonia root rot, caused by *R. solani* AG8, *R. oryzae*, and *R. cerealis*. These root diseases occur in various mixtures in wheat and barley fields of the Inland Northwest and collectively cause major damage to these crops, especially when these crops are direct-seeded into cereal stubble. Best control is achieved with 3- and 4-year crop rotations that include broadleaf crops alternated with wheat and barley. The practices are also now becoming available to manage these root diseases on wheat and barley seeded directly into wheat or barley stubble. These practices are:

- Eliminate volunteer and grass weeds (the green bridge) in the stubble early, especially for spring cereals seeded directly into cereal stubble, since theses plants can serve as hosts for wheat and barley root pathogens;

- Use “new” seed, preferably current year seed, but no older than 1 to 2 years old, since older seed is more vulnerable to damage caused by *Pythium*;

- Treat the seed with a combination of products active against all three root diseases, including, as options, Dividend/Apron or Raxil/Thiram, remembering that seed treatments provide protection mostly against seed and very early root infections;

- At the time of planting, place fertilizer and especially the phosphorus directly beneath and 1-2 inches to the side of the seed where these nutrients will be readily accessible to the seedling roots, even if the roots are damaged by root diseases;

- Plant the new rows at an angle--any angle up to 90 degrees--to the direction of the previous year’s rows, to maximize the amount of seed placed between rather than directly within the rows of old stubble where inoculum of root pathogens is most concentrated;

- Provide for soil disturbance below the seed and not just to the depth of the seed, which helps reduce the amount of infection by *Rhizoctonia*; and

- Clear trash from within the seed row, which also helps reduce infection by *Rhizoctonia*, possibly by exposing the soil surface in the row to slightly greater warming and drying.

While mixtures of root diseases are the rule and not the exception, the importance of any one component in the disease mixture can vary with soil conditions and cropping practices. For example, the more acidic clay type soils typical of the very southeastern edge of Washington and adjacent northern Idaho favors Pythium, whereas the neutral-alkaline, lighter-textured soils favor *R. solani* AG8. Barley in the rotation favors *R. solani* AG8, wheat favors take-all, and peas favor *Pythium ultimum*. We find heavy pressure from both *Pythium* and *Rhizoctonia* on wheat after bluegrass. A treatment designed to control just one component can sometimes favor another component in the disease mixture. Our research program is continuing to a) identify and learn more about the species and subspecies of wheat and barley root pathogens; b) find out more about how soil conditions and practices favor different mixtures of these pathogens; and c) develop the means to control the entire mixture.

Seed treatment chemicals are available to control components but not all of the pathogen-mixture responsible for seed infections and seed rot, and they do little to protect against any of the pathogens responsible for root rots. For example, Apron controls *Pythium* attack of seeds, but can leave the germinating seed vulnerable to attack by *Rhizoctonia*. A combination of Dividend + Apron or Raxil + Apron controls both pathogens on seeds and very young seedlings, but the plants are still vulnerable to take-all as well as root infections by *Rhizoctonia* and *Pythium* species. Thiram and Captan control seed-infecting pathogens only, although neither of these fungicides is as effective as Apron against *Pythium*. Dividend on seed controls seed infection and possibly some root infection by *Rhizoctonia* and take-all but has no affect on *Pythium*. We are continuing to test existing new seed treatment fungicides for activity against one or more of the wheat and barley root pathogens.

The good news is that one of the three root diseases, namely take-all, subsides and eventually all but disappears from fields cropped continuously to wheat. This remarkable phenomenon -- nature's alternative to the crop rotation effect and known as "take-all decline" -- has been observed wherever wheat is grown throughout the temperate world. We have documented take-all decline in many fields in the Inland Northwest, including with long-term direct-seeding (no-till) after 12-15 years of intensive wheat and barley.

Unraveling the mechanisms responsible for take-all decline has revealed one of the most fascinating soil microbiological processes ever discovered. To encapsulate: after one or more outbreaks of take-all, and with continued cropping to wheat (or barley), the make-up of soil bacteria in the rhizosphere (rhizobacteria) gradually shifts towards types that produce antibiotics inhibitory to the wheat take-all fungus. This is a natural defense system provided by rhizobacteria that forms a kind of symbiosis with the roots of wheat. The work shows further that the strains responsible for this defense are both highly adapted as wheat root colonists and they produce the antibiotic 2,4-diacetylphloroglucinol. We now have a gene test that allows us to identify where the populations of this particular antibiotic-producing rhizobacteria are sufficient to control take-all.

The obvious practical direction to go with our research is to develop the technology for introduction of these bacteria into the rhizosphere of wheat. We began to investigate this approach in the early 1980s, including field tests in cooperation with growers. All of our tests have been on winter and spring wheat seeded directly (no-till) into cereal stubble--conditions under which root disease control is needed most. Our biggest challenge has been to find the right strains. Our program has moved progressively though a succession of strains always selecting for better strains. The process is similar to breeding and selecting new varieties of crops.

One problem with the naturally occurring bacteria responsible for take-all decline is their antibiotic controls take-all but not Rhizoctonia or Pythium root rots. Other antibiotics are needed to protect wheat from these root diseases. During the past year, we tested one of our best phloroglucinol-producing strains engineered to express genes from another rhizobacterium for production of an antibiotic more inhibitory to Rhizoctonia and Pythium. This "transformed" strain with ability to produce TWO antibiotics produced a 16% yield increase over the parent types that made only one antibiotic. Both the U.S. EPA and the WSU BioSafety Committee approved our proposed field test with this engineered strain, which was planted on the WSU Plant Pathology Farm in late April, 1998. Two more tests are underway on spring wheat in 1999.

Future efforts will continue to concentrate on combining our best strains of biocontrol bacteria with the seed-treatment chemicals with best cultural practices for root disease control in no-till systems. Ultimately, we expect to have varieties of wheat and barley with resistance to at least some of the root pathogens to complete the package.

Our research has been supported by the Washington and Idaho Wheat Commissions, the Washington Barley Commission, the O.A. Vogel Wheat Research Fund, the USDA's National Research Initiative Competitive Grants Program, and many growers and agribusiness cooperators.

Two of our strains and their use were licensed in early 1999 to separate companies that will develop the technology for commercial use. One of the strains is typical of the type responsible for take-all decline. The other strain (Bacillus sp. L324-92) has natural broad-spectrum activity against soilborne pathogens but is not of the type responsible for take-all decline; the company with the license to this strain is intending to use it for disease control on turf.

Integrating Weed Management Using Seed Size, Seeding Rate, and Cultivar Plant Height to Enhance Winter Wheat Competitiveness Against Jointed Goatgrass (*Aegilops cylindrica*)

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Integrated crop management has been suggested as a means to reduce herbicide use by increasing crop competitiveness. While it is known that a healthy crop is more competitive than a sickly crop, the value of individual integrated crop management components is not fully understood. Farmers and researchers need to better understand not only the value, but also the cost of integrated components.

A study was conducted to determine if wheat variety height, seed size, and seeding rate, affect the competitiveness of winter wheat against jointed goatgrass. The research was conducted at the USDA-ARS Palouse Conservation Field Station beginning in the fall of 1997.

Two isolines of a soft white winter wheat variety 'Nugaines' were used to determine competitive effects due to height. Heights at maturity are 3 and 4 feet for the short and tall isolines, respectively. Using isolines ensured a similar genetic make-up with exception of plant height.

Seed of the tall and short wheat were separated by size into large and small lots. Large seed was not able to pass through a 11/64 inch mesh screen. Small seed lots passed through 11/64 and 10/64 inch screens but did not pass through a 9/64 inch mesh screen. In addition to the large and small lots the original mixed seed lot was used as a treatment.

Seeding rates of 1.0 and 1.5 seed per inch of row were used to determine seeding rate effects on crop competitiveness. These rates are equal to 70 and 105 lbs/A, respectively, for the mixed seed lot as seeded in 7-in rows.

Wheat was seeded on October 10, 1997 and stand density was measured at biweekly intervals from October 27 through the end of November when plants became dormant (Table 1). Stand density was measured again on February 19, 1998. After this date we were unable to accurately count individual plants. As expected, stand establishment was greater with 1.5 than 1.0 seed/in. of row. Also, stand establishment was more rapid using large seed compared to small seed. Rapid seedling emergence and vigorous seedling growth greatly increase the competitiveness of a crop against weeds. Using greater seeding rates and larger seed are a method of increasing the competitiveness of the crop during the critical early stage of crop development. Emergence was not affected by variety height.

Wheat and jointed goatgrass heights were measured at three week intervals beginning March 20, 1998 (Table 2). Measurements were not taken after May 20, because wheat stems had begun elongating, as indicated by jointing, prior to May 7. Height measurements of mature wheat were taken July 1. Jointed goatgrass was not measured on this date because additional handling of the weed would have shattered the heads. Wheat height measurements taken prior to stem elongation indicated little to no effect of variety height or seeding rate on seedling height. However, large seed size had greater wheat seedling height prior to stem elongation relative to the small and mixed seed lots. This could be an indication of greater early seedling vigor with wheat grown from larger seed and may have implications to plant competition. Height difference between short and tall wheat is not expressed until true stem elongation occurs. The tall wheat variety was not measurably taller than the short variety until the May 7 measurement. Therefore, competitive effects from tall wheat would not have impacted jointed goatgrass until sometime after April 27 or late in the development of the crop and weed. Jointed goatgrass height measurements were not influenced by variety height, seed size, and seeding rate. However, jointed goatgrass height may not be a true indicator of crop competitiveness. Final measurements of crop and weed biomass, density, and seed production are more indicative of competitive effects.

Measurements of wheat and jointed goatgrass whole plant biomass and head density and jointed goatgrass spikelet production were measured at wheat harvest (Table 3). As expected, tall wheat had greater whole plant biomass at harvest because of the longer stems. Whole plant wheat biomass was greater with the large seeded wheat than small and mixed seed lots. Apparently, the greater vigor of the large seed treatment sustained itself through crop maturity. Seeding rate had no effect on total biomass. Wheat height and seeding rate had no effect on head density, but large seeded wheat had more heads per m^2 than small or mixed seed lots.

Jointed goatgrass biomass, head density, and spikelet production were affected by seed size and seeding rate, but only biomass and spikelet production were affected by variety height (Table 3). The large seed treatment had less jointed goatgrass biomass, heads/m^2, and spikelet production than either small or mixed seed lots. Likewise, the greater seeding rate resulted in less jointed goatgrass biomass, head density, and spikelet production than the standard rate. Taller wheat resulted in less jointed goatgrass biomass and spikelet production, but not less head density.

Wheat height is the most important factor of those examined to final grain yield. The short wheat greatly out-yielded the tall wheat (Table 4). However, dockage due to jointed goatgrass in the harvested wheat was much greater with short wheat. While short wheat may be less competitive than tall wheat, as indicated by greater jointed goatgrass dockage, it may also be more tolerant to weed competition that taller wheat, as indicated by greater yield. The competitiveness of short wheat may be increased by using large seed and increasing the seeding rate. The competitiveness of taller wheat can also be increased by using large seed and increased seeding rate, but the response is not as great as with short wheat.

In summary, growers can increase the competitiveness of a crop through integrated crop management. Herbicide use may be decreased by increasing crop competition which reduces input cost per acre. However, increased competitiveness may result in decreased yields which reduces return per acre. Growers need to evaluate their crop and weed management goals to determine best use of integrated crop management. Meanwhile, research will continue at WSU to determine the weed management value and return of each component of an integrated crop management program.

Table 1. Winter wheat seedling density as affected by isoline height, seed size, and seeding density

	Winter wheat stand density		
Main effect	October 27	November 10	February 19
	Plants/m of row		
Variety height			
Short	10	21.3	31.5
Tall	11.7	22.7	30.7
LSD (p=0.05)	ns	ns	ns
Seed size			
Large	12.2	24.6	34.3
Small	8.9	19.6	27.1
Mixed	11.4	21.8	31.9
LSD (p=0.05)	ns	2.8	2.5
Seeding rate			
1 seed/in.	8.9	18.0	26.6
1.5 seed/in.	12.7	25.9	35.6
LSD (p=0.05)	2.6	2.3	2.1

Table 2. Winter wheat and jointed goatgrass height as affected by isoline height, seed size, and seeding density

	Winter wheat height						Jointed goatgrass height				
Main effect	Measurement date						Measurement date				
	3/20	4/9	4/27	5/7	5/20	7/1	3/20	4/9	4/27	5/7	5/20
	---------- cm ----------						---------- cm ----------				
Variety height											
Short	14.8	23.6	33.1	51.7	92.4	98.9	5.3	10.6	15.4	45.5	109
Tall	13.9	20.9	32.9	61.3	122.8	134.6	5.4	10.1	12.9	47.0	104
LSD (p=0.05)	ns	1.2	ns	7.5	4.1	2.7	ns	ns	1.8	ns	ns
Seed size											
Large	15.3	24.6	36.0	58.2	110.3	118.7	5.3	10.6	14.8	46.9	110
Small	13.4	20.2	30.1	52.0	106.2	115.6	5.3	10.0	13.0	43.9	113
Mixed	14.0	21.9	33.0	59.2	106.4	116.0	5.5	10.3	14.7	47.9	112
LSD (p=0.05)	1.2	1.5	2.8	ns	ns	ns	ns	ns	ns	ns	ns
Seeding rate											
1 seed/in.	14.5	21.5	32.7	53.9	106.3	117.4	5.4	9.9	13.6	45.4	109
1.5 seed/in.	14.2	22.9	33.4	59.0	109.0	116.2	5.3	10.7	14.7	47.2	115
LSD (p=0.05)	ns	1.2	ns	ns	ns	ns	ns	ns	ns	ns	ns

Table 3. Wheat and jointed goatgrass total biomass and head density at maturity

Main effect	Winter wheat		Jointed goatgrass		
	Biomass	Head density	Biomass	Head density	Spikelet production
	g/m^2	no./m^2	g/m^2	no./m^2	g/m^2
Variety height					
Short	550.0	610.6	73.8	569.3	16.0
Tall	617.9	668.0	42.3	438.6	4.9
LSD (p=0.05)	37.6	ns	16.8	ns	3.6
Seed size					
Large	636.4	705.3	43.9	370.6	8.1
Small	564.1	624.0	75.4	650.6	13.6
Mixed	551.2	558.0	54.7	490.6	9.7
LSD (p=0.05)	46.1	89.3	20.5	165.3	4.4
Seeding rate					
1 seed/in.	565.2	614.6	75.3	630.6	13.9
1.5 seed/in.	602.6	664.0	40.8	377.3	7.0
LSD (p=0.05)	ns	ns	16.8	134.6	3.6

Table 4. Winter wheat yield and dockage due to jointed goatgrass

Main effect	Winter wheat yield	Dockage due to jointed goatgrass
	bu./acre	%
Variety height		
Short	107	12.1
Tall	70	2.3
LSD (p=0.05)	6	1.7
Seed size		
Large	90	7.2
Small	86	5.3
Mixed	88	9.1
LSD (p=0.05)	ns	2.1
Seeding rate		
1 seed/in.	85	9.3
1.5 seed/in.	92	5.1
LSD (p=0.05)	6	1.7

Strawbreaker Foot Rot, Cephalosporium Stripe and Snow Mold Diseases of Winter Wheat

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Strawbreaker foot rot (also known as Eyespot) and Cephalosporium stripe are two of the most important diseases of winter wheat in the Inland Pacific Northwest. These diseases are most common in the high rainfall areas (more than 18" annual precipitation), but can cause significant losses in the lower rainfall areas too. Early-seeded winter wheat has the greatest risk of being affected by these diseases, especially when planted following summer fallow. Grain yield in fields where either of these diseases is severe may be half or less than that of fields where these diseases are not serious. The snow mold diseases are limited to the northernmost wheat-producing areas of Lincoln, Douglas, and Grant Counties and southern Okanogan County where snow cover frequently persists for 100 days or more. Left uncontrolled, all of the plants in a field can be killed when snow mold is severe.

Disease-resistant varieties are the most desirable control measure for all three of these diseases. Varieties with resistance to strawbreaker foot rot and the snow molds are available and used widely. Varieties with resistance to Cephalosporium are not currently available, however.

Cephalosporium stripe is controlled by delaying seeding in the fall (in fields seeded early relative to the production area), increasing the length of crop rotation so that winter wheat is grown one year in three, and by increasing tillage to promote decomposition of crop residue infested with the pathogen. None of these practices completely controls the disease, and all may have undesirable consequences such as increased soil erosion potential or decreased yield potential.

Growing disease resistant varieties is the most reliable method of controlling Cephalosporium stripe; however, true resistance to this disease does not exist in cultivated wheat. Several winter wheat varieties adapted to the Inland Pacific Northwest have been identified that are tolerant of the disease (Table 1). Eltan has had the greatest yield and the least Cephalosporium stripe of the commercial varieties tested over the past several years. A better source of resistance to Cephalosporium stripe has been found in the wheat x wheatgrass hybrid AT3425. Crosses have been made between AT3425 and local varieties to transfer the resistance from this wild relative into wheat. Studies are in progress to determine the number and location of genes in AT3425 conferring resistance to Cephalosporium stripe to aid in transferring resistance to adapted winter wheat lines. Ultimately, we want to develop molecular markers for these resistance genes in order to accelerate the development of Cephalosporium stripe resistant varieties. Molecular markers are tags placed on the resistance genes that allow us to follow them in crosses and determine which progeny plants have the resistance genes without the need to test them for resistance in field plots.

A foliar fungicide applied in the spring before jointing and the use of the foot rot resistant variety Madsen are the two most common tools used for control of strawbreaker foot rot. Although the level of resistance in Madsen is very effective for controlling strawbreaker, additional resistant varieties adapted to intermediate- and low-rainfall areas are needed. We developed the GUS seedling test to screen wheat for resistance to Strawbreaker foot rot in the greenhouse. This test, which can be completed in two months, is being used to identify and transfer new sources of resistance in wild relatives of wheat to cultivated wheat. To date we have identified and named two new genes for resistance to strawbreaker. In conjunction with Dr. Stephen Jones, winter wheat breeder, we are in the process of transferring these genes to adapted winter wheat varieties. Our first goal is the development of and Eltan-like wheat with resistance to strawbreaker foot rot.

Fungicides will continue to be an important tool for strawbreaker control until resistant varieties adapted to all production areas of Washington State are available. Last year about 200,000 acres in Washington were treated with a fungicide for control of strawbreaker. We tested several fungicides in a field plot near Ritzville, WA on Eltan winter wheat. Nearly 100% of the stems had strawbreaker foot rot at the time of fungicide application on April 7, 1998. There were significant differences among treatments for disease control (Table 2), however there were no significant differences in yield or test weight due to an abundance of Barley Yellow Dwarf in the plot.

The WSU Variety Release Committee approved the new snow mold resistant club wheat variety Bruehl for full release in February 1999. Bruehl has the advantages of snow mold resistance that is equal to Sprague and yield potential equal to or greater than Eltan. Bruehl is the first snow mold resistant club wheat released in Washington State. A continued effort will be maintained for the development of new, more resistant varieties for the snow mold areas of the Washington State. Research is in progress to develop a method of screening for resistance in the growth chambers in the Wheat Plant Growth Center. Such a method would expedite the development of resistant varieties by allowing disease screening to continue throughout the year.

Table 1. Cephalosporium Stripe Variety Trial, WSU Agronomy Farm 1998

Variety	Market	Disease	Yield	Test Wt.
AT3425 [b]	Perennial	1.8	35.1	10.9
WA7437	Club	8.0	73.5	24.0
Eltan	SWW	14.6	82.5	29.8
Sprague	SWW	15.5	52.5	22.6
Rod	SWW	18.7	93.6	34.7
Bruehl	Club	20.0	96.9	36.4
Rely	Club	23.8	73.5	32.6
Edwin	Club	27.0	41.9	26.7
Lewjain	SWW	28.8	74.1	35.7
Moro	Club	42.0	38.0	33.9
Madsen	SWW	43.5	107.4	51.4
Stephens	SWW	62.7	63.8	50.3
Malcolm	SWW	76.7	50.6	54.6
LSD [c]		17.0	19.8	1.7

[a]- Disease index ranges from 0 to 100 and is a combination of the percent infected stems and disease severity on those stems. A 0 represents no disease and 100 is uniformly severe disease. Larger numbers are associated with greater yield loss.

[b]- AT 3425 is a wheat-wheatgrass hybrid that is perennial.

[c]- Least significant difference: Two figures in the same column must differ by this amount to be considered statistically different.

Table 2. Disease index, yield and test weight of Eltan winter wheat treated with foliar fungicides for the control of strawbreaker foot rot on the Manke farm, Rtizville, WA 1998

Treatment[1]	Rate,	Disease	Yield	Test Wt.
RH7592 + Benlate +	0.19 lb + 0.25 lb +	32.6	42.1	59.7
RH7592 + Benlate +	0.125 lb + 0.25 lb +	35.8	43.3	60.7
Tilt + Topsin 4.5 SC	1.7 oz + 0.35 lb	45.1	41.4	60.7
Tilt + CGA219417	1.7 oz + 0.45 lb	50.8	36.8	59.5
Tilt + Mertect 340-F	1.7 oz + 0.56 lb	54.3	41.9	60.3
Tilt + CGA219417 +	1.7 oz + 0.34 lb + 0.125%	55.2	44.3	60.2
Tilt + Mertect 340-F	1.7 oz + 0.42 lb	57.5	38.9	59.6
Tilt + CGA219417	1.7 oz + 0.34 lb	57.7	39.8	59.8
RH7592 + CS7	0.19 lb + 0.125% (v/v)	61.9	39.0	59.9
RH7592 + CS7	0.125 lb + 0.125% (v/v)	62.5	40.9	60.3
Tilt + CGA219417	1.7 oz + 0.22 lb	63.7	39.1	59.3
Untreated Control		66.5	35.6	58.9
LSD		14.2	n.s.	n.s.

[1]- Fungicides were applied April 7, 1998 in 20 gpa of water.

[2]- Disease index is a measure of both disease incidence and severity and ranges from 0 to 100, where 0=no disease on any stem and 100=all stems with severe disease. Larger numbers are usually associated with greater yield loss. Disease evaluations were made 8 June when plants were in the watery-ripe stage of kernel development.

Russian Thistle: Water Use and Growth after Wheat Harvest

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Interpretive Summary: Russian thistle (*Salsola iberica*) is a major broadleaf weed in dryland crops (less than 12 inches annual precipitation) in the Pacific Northwest of the USA. Russian thistle frequently infests sparse winter wheat stands, especially during drought, and spring-planted crops. After grain harvest, Russian thistle produces substantial dry matter and seed, and extracts soil water until killed with herbicides, tillage, or by frost. In a 2-year study at Lind, Washington, 100 Russian thistle plants were allowed to grow yearly in a grid pattern. Each Russian thistle occupied 400 ft^2 without competition from other weeds from April until hard frost in October. After wheat harvest in early August, volumetric water content was measured at 13-day-average intervals to a soil depth of 6 ft at distances of 1, 2, 3, 5, and 10 ft from the base of six target Russian thistles. On every measurement date, six Russian thistle plants of similar size within the experimental area were gathered to determine dry biomass accumulation, number of seeds per plant, and percent viable seeds. Individual plants used 19 gallons of soil water while growing with the crop. From harvest until late October each Russian thistle used an additional 27 gallons of soil water. Water use occurred within a 5 ft radius of the Russian thistle. Spring wheat competed with Russian thistle for water at shallow soil depths; most water use by Russian thistle was from deeper than 3 ft. Russian thistle dry weight increased from 0.4 to 2.8 lb. per plant between grain harvest in August and frost in October. Production of viable Russian thistle seeds did not begin until mid-September during either year. By the time of killing frost in late October, individual plants had produced 67,000 and 25,000 seeds in 1996 and 1997, respectively.

Conclusions: Water is the most limiting factor in dryland crop production regions where Russian thistle is the dominant broadleaf weed. Russian thistle aggressively extracts soil water beyond the available range of spring wheat as well as from deeper soil depths than spring wheat. If not controlled with herbicide or V-blade sweeps after wheat harvest, substantial soil water loss will continue until plants are finally killed by frost. Soil water recharge was reduced within a 5-ft radius of individual Russian thistles after a winter of greater than average precipitation, but over-winter water recharge was not significantly affected by Russian thistle when winter precipitation was close to the long-term average and water infiltration occurred only to a soil depth of about 3 feet.

Dry Russian thistle biomass increased seven fold and individual plants produced an average 46,000 seeds between early August and late October. Seeds were either not produced or viable in appreciable quantities until mid-September, therefore, there is an ample post-harvest window to control the spread of this weed. An important management question is: If allowed to grow post-harvest (before production of viable seed) for erosion control when crop residues are extremely lacking, might water use by Russian thistle be compensated by increased over-winter precipitation storage due to greater quantity of surface residue? In other words, how can Russian thistle be best managed post-harvest to benefit from the plant biomass without negatively impacting the subsequent crop?

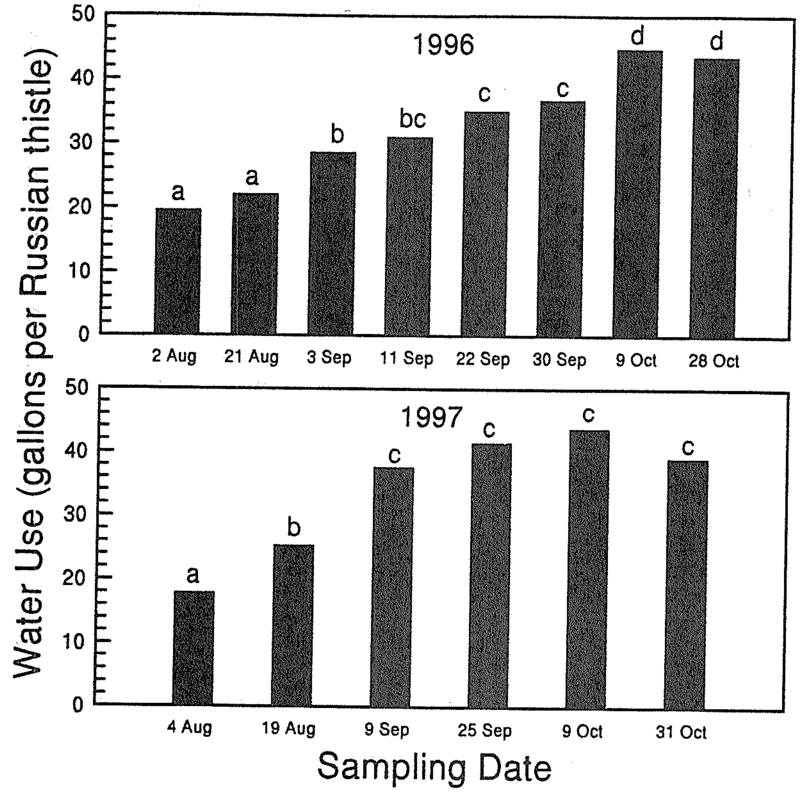

Fig 1. Post-harvest soil water use by undisturbed Russian thistle in spring wheat stubble from wheat harvest in early August until killing frost in late October in 1996 and 1997.

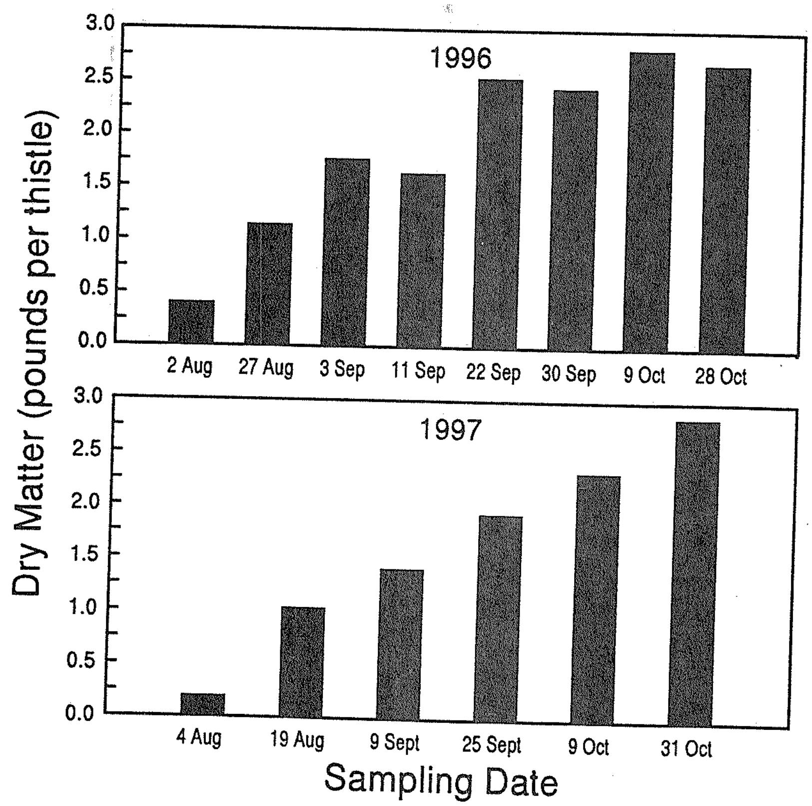

Fig. 2. Post-harvest dry matter accumulation of Russian thistle plants when allowed to grow undisturbed and without competition in spring wheat stubble from early August until late October in 1996 and 1997.

The Smuts and Bunts of Wheat: a New Perspective

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Common Bunt. Common bunt (stinking smut), caused by the fungus *Tilletia tritici*, is a disease characterized by replacement of the normal wheat kernel with bunt balls containing a black, powdery mass of spores. For the first half of the twentieth century, common bunt was considered to be the most important disease of wheat in the Pacific Northwest. Massive clouds of sooty black spores released during harvest were a common sight in the region. When severe, the disease totally destroyed the wheat crop. When less severe, grain harvested from fields with bunt was contaminated with the spores and had a fishy odor and a darkened appearance. When that grain was milled, it produces off-white flour, which affected its market value. Wheat graded as smutty received a lower price because of the cost of cleaning the grain. During the mid 1940s, more than 40% of the grain brought to the local elevators was graded as smutty. The large masses of spores released during harvest were easily ignited by sparks and frequently caused explosions and fires in threshing machines, combines, and grain storage facilities. Such fires destroyed machinery and crops and were a danger to people working in the area.

In addition to the destruction of a major food crop and the detrimental effect of the disease on the economy of the region, the air-borne spores released into the atmosphere caused respiratory problems for people who were allergic to the spores. The disease was so important that the Pacific Northwest became known by agriculturist and scientists as the smut capital of the world.

In most regions of the world, spores on the seed are the major source of inoculum. Under the right environment, the spores germinate and infect the plant before the wheat seedlings emerge. The fungus grows within the plant and replaces the normal wheat kernel with bunt balls containing a black, powdery mass of spores. The Pacific Northwest, however, has a unique environment that allows the pathogen to survive in the soil as well as on the seed. Thus, many of the methods used to control the disease in other regions were not adequate for control of the disease in the Pacific Northwest. Use of seed protectants did not prevent infection by the fungus in the soil, and adjusting planting dates and other management practices only reduced disease severity. Use of resistant varieties was at best short-lived. Within a few years after the release of a new resistant variety, new races of the pathogen that could circumvent that resistance evolved.

The discovery that polychlorobenzenes, such as hexachlorobenzene (HCB) and pentachloronitrobenzene (PCNB), would control soilborne common bunt was a major break-through in the 1950s. Use of those seed treatments has reduced common bunt from the most important disease of wheat in the region to a disease of minor importance. The treatments not only controlled common bunt but also extended the life of resistant varieties by delaying the appearance of new races. More recently, new fungicides have effectively controlled the disease.

Flag Smut. Flag smut caused by the fungus *Urocystis tritici* was first detected on wheat in the Pacific Northwest in 1940. During the following 20 years, the disease spread to additional counties of eastern Washington and Oregon, but little was done to control the disease primarily because other diseases were more important, especially common bunt.

When I arrived in the Pacific Northwest in 1968, flag smut was the most important disease in Klickitat County, WA and Wasco County, OR and had spread to several other counties of the two states. Like common bunt, clouds of flag smut spores were often observed during harvest. It was common for flag smut to cause annual losses of 10% or greater. Many of the commercial varieties grown in the region were susceptible and several new varieties that were being considered for release were also susceptible. The seed treatments that were so highly effective for control of soilborne common bunt did not control soilborne flag smut. Information on the epidemiology and control of the disease was inconsistent, often contradictory, or unavailable; and the distribution and potential destructiveness of the disease was not clear. To add to the problem, there was concern about the effect of the disease on the export market, since some countries have quarantines against importing grain contaminated with flag smut.

Like common bunt, flag smut survives in the soil as well as on the seed and infects the plant before emergence. However, the disease does not appear in the heads. Flag smut appears as gray-black stripes between the veins of leaf blades and sheaths. Infected plants are usually dwarfed with distorted and twisted leaves. When severe, heads never develop.

Research on control of flag smut was initiated in 1968. By 1972, the environmental and managerial factors that contributed to severe flag smut were determined and the disease was controlled. The major break-through was the discovery that two, new systemic seed treatments, oxycarboxin (Plantvax) and carboxin (Vitavax), would provide complete control of flag smut. Carboxin became the registered treatment, because it was also effective against common bunt. Because of the use of carboxin, flag has become an insignificant disease of wheat in North America and is no longer a threat to the marketing of wheat from the Pacific Northwest. More recently, newer seed treatments have been developed that control flag smut at lower rates. The quarantine regulations have been reassessed and are expected to be eliminated. Thus, an impediment to international exchange of wheat and barley germplasm will be removed.

Loose Smut. Loose smut, caused by the fungus *Ustilago tritici*, is most obvious when new heads emerge. The disease first appears as deformed spikelets filled with a dry, dusty, powdery mass of black spores enclosed by a fine membrane. The membrane quickly disintegrates, and within a few days, only the bare spike with a few black spores remains. The exposed spores are dispersed by wind to newly emerging healthy heads where they germinate and infect the plant when the spikelets open for pollination. The fungus develops in the embryo as the seed develops and becomes dormant as the seed ripens. The pathogen remains dormant within the seed until the seed germinates. Then it grows along with the plant and ultimately occupies the developing spike. Therefore, infection that occurs in one year does not produce smutted heads until the next year.

Loose smut had been difficult to control for centuries primarily because it is dormant within the seed embryo. Applications of protectants to the seed surface were ineffective, and other treatments that penetrated the seed were difficult to use. The break through in the control of loose smut was also seed treatment with the systemic fungicide, carboxin.

Dwarf Bunt. Dwarf bunt, caused by the fungus *Tilletia controversa* and also called dwarf smut or TCK smut, is similar to common bunt, except that it infects tillers of wheat plants in the winter under snow at temperatures near freezing, and it can survive in the soil for many years. Because of those characteristics, the disease was not controlled by the seed treatments that were effective in controlling common bunt, flag smut, and loose smut. Planting very early or very late in the fall and combining several genes for resistance into one variety reduces losses in yield caused by dwarf bunt but does not provide complete control and does not prevent contamination of the grain.

For 27 years, the People's Republic of China had a quarantine to prevent the import of grain contaminated with dwarf bunt spores. Thus, a few spores in a grain sample could affect international marketing of wheat from a region, even when the disease did not significantly reducing yield in that region or reduce flour quality. Such restrictions have had the effect of eliminating a major world market. Results of our recent research show that a new systemic seed treatment, difenoconazole (Dividend), provided complete control of dwarf bunt under a wide range of environmental and managerial conditions. The new treatment was registered in the summer of 1994 and was used extensively to treat fall planted wheat in 1994 and 1995. The fungicide is now used in many areas of the region. Because of that research, grain graded as smutty is now rare. That breakthrough was a factor that contributed to opening the wheat export market. Utilizing knowledge of the epidemiology and control of cereal diseases to provide the key biological reasons why TCK was not a potential risk to the Peoples Republic of China and the removal of their trade barrier against wheat from the Pacific Northwest. It was also the basis for removal of the Brazilian and Mexican quarantines, and the possible removal of the Indian trade barrier.

Karnal Bunt. Karnal bunt (partial bunt), caused by *Tilletia indica*, is a new smut disease of wheat in the United States. Karnal bunt is a disease that occurs under the environmental conditions that occur in India, Pakistan Nepal, and Mexico and is seldom severe and seldom affects grain quality even in those countries. The disease was detected in Arizona and California in regions adjacent to Mexico in March 1996 and in Texas in 1997. A smut of ryegrass that has spores that looked similar to the Karnal bunt spores was found in grain samples in the southeast and thought to be Karnal bunt. However, it proved to be a different pathogen. The Karnal bunt spores survive in the soil and germinate when wet to produce a type of spore that is carried to wheat heads where infection occurs. Because of its environmental requirements for survival, germination, and infection and the limited period when the wheat plant is susceptible, Karnal bunt is not expected to become a production problem in the Pacific Northwest or in other regions of northern United States. It should not affect yield or quality in those regions. However, because of national and international quarantine regulations, the disease has an impact on the marketing of wheat. It is to the southwestern United States what dwarf bunt was to the Pacific Northwest.

Some seed treatments reduce the spread of Karnal bunt, but none of the currently registered seed treatments provide 100% control of the bunt. Future control of Karnal bunt on seed will depend upon the ability of the seed treatments to kill all spores in and on the wheat seed or in the soil or to kill all germination spores. Some systemic foliar fungicides prevent infection of the heads or prevent disease development in the field. There is a need for research aimed at elucidating the epidemiological factors affecting the disease in order to understand its importance to the wheat industry and implement control methods.

General Comments Regarding Control of Smuts and Bunts. Quarantine regulations have proven to be ineffective and unnecessary for control of the smuts and bunts. Whereas, use of resistant cultivars, and management, has controlled the diseases. The use of seed treatments for the control of smuts and bunts is the best example of the effectiveness, value, usefulness, and importance of chemicals for control of cereal diseases. Several seed treatments provide outstanding control of common bunt, flag smut, and loose smut with essentially no adverse environmental impact and a minimum cost to the grower. Difenoconazole provides similar control of dwarf bunt. Seed treatments and foliar fungicides control Karnal bunt. Use of chemical seed treatments has prevented world-wide crop losses and saved the economy of the Pacific Northwest while preventing pollution of the environment with bunt and smut spores. The newest systemic seed treatments control the diseases at rates lower than 0.5 ounces per acre, rates that have essentially no affect on the environment. If the seed treatments were not available, those diseases would return to their former importance, and the economy of the Pacific Northwest would be drastically affected.

Wheat and Barley Stripe, Leaf and Stem Rust

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General Characteristics. Three rusts (stripe rust, leaf rust, and stem rust) occur on wheat and barley in the Pacific Northwest. Stripe rust appears as golden-yellow, long, narrow stripes on the leaf surface and glumes; leaf rust appears as small, red pustules on the leaf surface and leaf sheath; and stem rust appears on the stems and as large, red-brown, diamond-shaped pustules on the leaf surface. Stripe rust and stem rust can also occur on the heads. Stripe rust and leaf rust overwinter on wheat and barley and rapidly increase during the spring. Stripe rust develops during the cool temperatures of early spring. Leaf rust develops at warmer temperatures later in the spring. The stem rust pathogen does not usually survive on living plants during the winter. It survives as dormant spores on straw and depends upon the common barberry for completion of its life cycle. In the spring, the dormant spores germinate and produce another type of spore that infects barberry leaves but not wheat. Spores produced on the barberry are the source of inoculum in the spring. Therefore, eliminating the barberry would eliminate or reduce stem rust.

Historical Importance. In the late 1950s and early 1960s stripe rust caused losses in excess of 70 percent. When not controlled, stripe rust has caused losses of 20% or more in three out of four years and every year in western Washington. A new form of *Puccinia striiformis* that attacks barley (barley stripe rust) is now present in the West. Barley stripe rust looks like wheat stripe rust but is a different pathogen that is more severe on barley. Barley stripe rust can damage barley in the same manner that wheat stripe rust has damaged wheat.

As we developed wheat varieties with better stripe rust resistance, leaf rust became more important because tissue not damaged by stripe rust is damaged by the later developing leaf rust. Consequently, leaf rust became increasingly more important after 1962. When not controlled, leaf rust has can reduce yields by more than 20% in one out of two years and every year in irrigated fields. Stem rust is less frequently severe, but when present, it can cause major damage to both wheat and barley.

Rust forecasting. The rusts are obligate parasites and must have a living host to grow on. The continual presence of living plants throughout the year provides hosts for the rusts and inoculum for initiating new stripe rust and leaf rust epidemics. Therefore, the most limiting factor affecting rust development is often the weather. A monitoring program was implemented to provide early warnings to breeders and growers so that they could take action to prevent major losses. Since 1979, the use of predictive models and monitoring data has accurately forecasted wheat stripe rust, leaf rust, and stem rust, and more recently forecasted barley stripe rust.

Races of the stripe rust pathogens are identified by the varieties that they attack, and new races of the pathogens frequently evolve to attack varieties that were previously resistant. Figure 1 lists the 57 races of the wheat stripe rust pathogen that were detected in North America before 1996. In addition to the wheat stripe rust races, there are at least 31 barley stripe rust races.

TABLE 1. VIRULENCE OF CEREAL DISEASE LABORATORY (CDL) STRIPE RUST RACES ON WHEAT DIFFERENTIALS.

DIFFERENTIAL NO.	NAME
1	Lemhi
2	Chinese 166
3	Heines VII
4	Moro
5	Paha
6	Druchamp
7	Riebesel 47-51
8	Produra
9	Yamhill
10	Stephens
11	Lee
12	Fielder
13	Tyee
14	Tres
15	Hyak

RACES OF PUCCINIA STRIIFORMIS TRITICI, WHEAT STRIPE RUST								
CDL RACE	FIRST YEAR	VIRULENCE ON DIFFERENTIALS	CDL RACE	FIRST YEAR	VIRULENCE ON DIFFERENTIALS	CDL RAC E	FIRST YEAR	VIRULENCE ON DIFFERENTIALS
1		1,2	20	1977	1,6,8,10,12	39	1987	1,2,4
2	1963	1,2,5	21	1978	2	40	1989	1,4,14
3		1,3	22	1980	1,3,12	41	1989	1,3,4,14
4	1964	1,3,?	23	1981	1,3,6,9,10	42	1989	1,3,11,12
5	1968	1,3,4	24	1981	1,3,5,12	43	1990	1,3,4,5,12,14
6	1972	1,6,8,12	25	1981	1,3,6,8,9,10,12	44	1990	1,4,5
7	1974	1,3,5	26	1982	1,3,9,12	45	1990	1,3,12,13,15
8	1974	1,3,9	27	1983	1,3,12,13	46	1991	1,3,6,9,10,11
9	1975	1,3,6,8,12	28	1983	1,3,4,12	47	1992	1,6,8,12,13
10	1976	1,2,3,9	29	1983	1,3,4,5	48	1992	1,6,8,12,13,14
11	1976	1	30	1983	1,4,6,8,12	49	1992	1,3,11,14
12	1976	1,5,6,12	31	1983	1,3,5,11	50	1992	1,3,4,5,14
13	1976	1,5,6,8,12	32	1983	1,4	51	1992	1,3,4,12,14
14	1976	1,8,12	33	1984	1,3,9,12,13	52	1993	1,4,8,12,14
15	1976	1,3,6,8,10	34	1984	1,3,4,5,12	53	1994	1,6,10
16	1977	1,3,9,11	35	1985	1,10	54	1994	1,3,4,6,8,9,10,12
17	1977	1,2,3,9,11	36	1985	1,3,4,9,12	55	1994	1,6,10,11
18	1977	1,3,4,9	37	1987	1,3,6,8,9,10,11,12	56	1995	1,4,8,12,14
19	1977	1,3,6,8,10,12	38	1987	1,3,11	57	1996	1,3,4,6,8,10,12

Rust resistance. High-temperature, adult-plant resistance to stripe rust, which has now been incorporated into all major soft white winter wheats and most spring wheats has continued to be durable against all races in the Pacific Northwest. In contrast, resistance that is expressed at all temperatures in the seedling stage as well as adult stages has remained effective for three years or less. Information on the characteristics and inheritance of high-temperature, adult-plant resistance has been obtained, and that resistance has been or is being used to develop new resistant varieties. New information on the inheritance rust resistance and the location of genes for resistance has been obtained, and that information and that material should be useful in developing new disease control programs, identifying races, and understanding how resistance works. We annually evaluate wheat and barley selections from the National Germplasm Collection and commercial varieties and advanced breeding lines from breeders in the West for resistance to the rusts at sites near Mt. Vernon and Pullman, WA and in the greenhouse under controlled conditions. That information has made possible the development and release of rust resistant varieties and has provided breeders with new sources of resistance, lead to a better understanding of how to use rust resistance, and improved the resistance of wheat varieties.

Chemical control of the rusts. Resistance to all wheat and barley disease problems may be difficult or impossible to incorporate into a single variety, and new races of the pathogens are a frequent problem. Therefore, additional control measures are sometimes necessary. As part of an integrated disease control program, we have determined how to use fungicides for control of the rusts alone or in combination with other control methods. Results of those studies show that foliar applications of Bayleton, Tilt, Folicur, Spotless, Punch, Alto, Govern, or Quadris will control stripe rust, leaf rust and stem rust when applied at jointing to heading stages of growth. Treatment of seed with Baytan will prevent early stripe rust development. Guidelines on how to use the seed treatments and sprays were developed based on the type of rust, type of resistance, intensity of rust, stage of growth, potential yield, and economic return. A new expert system, MoreCrop 2.0, has been developed for managing wheat diseases.

Barley Stripe Rust Is In the Pacific Northwest

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A new barley disease, barley stripe rust (Puccinia striformis hordei), has appeared in the Pacific Northwest and can cause wide spread damage to barley in Washington and adjacent states. The disease can cause losses as severe as the losses that occurred in wheat during the early 1960s when there were no resistant cultivars and no other available methods of control.

Barley stripe rust is one of the many fungal diseases of cereals and grasses that are referred to as rusts. They get their names by the rust-like, powdery spores that are produced on the foliage of the plants. Stripe rusts appears on young plants as golden-yellow blotches with powdery spores and later as long, narrow golden-yellow stripes on the leaf surface and glumes. The stripes generally appear between leaf veins but can sometimes cover the entire leaf. The spores are carried by the wind to other leaves on the same plant, other plants, and plants in other fields. When the leaves are moist, the spores germinate, infect the leaves, and produce new spores. The cycle can be repeated many times in a growing season. Thus, the disease can start from a few infections and increase to completely cover the plant. The fungus can only infect and grow on living plants. Therefore, the presence of susceptible barley plants throughout the year contributes to the survival and spread of the pathogen.

Barley stripe rust is similar to the well-known wheat stripe rust (Puccinia striformis tritici); however, they are two different pathogens. Wheat stripe rust can attack cultivars of barley as well as wheat, but it has never been observed to cause severe damage to barley in the Pacific Northwest. In contrast, barley stripe rust is known to reduce barley yields by 30 to 100 percent and to greatly reduce the quality of the grain. Barley stripe rust is not known to damage wheat.

Barley stripe rust is a new disease in the United States. It was not known to be present in the United States until 1991. The disease is well known in Europe. Barley stripe rust was reported to be present in South America near Bogota, Columbia in 1975. It was postulated that people traveling from Europe introduced the barley rust into Columbia, since the race that was detected in Columbia was the same as race 24 that was common in Europe. The rust soon spread to other South American countries and eventually to Mexico. It caused widespread devastating losses in each of the regions where it occurred. The disease was first detected in Texas in 1991, and since then it has been spreading north and west. It appeared in Oklahoma, New Mexico and Colorado in 1992, and in Arizona in the spring of 1993, where it again caused major yield losses and greatly reduced malting quality. By August 1993, it was detected in southern Idaho and Montana. There were reports of stripe rust on barley in California in 1993, but the disease was not positively identified in California until 1994. Barley stripe rust also appeared in Utah in 1994 and 1995 and caused severe damage. By the spring of 1995, the disease had appeared in northwestern Washington and western Oregon, and by July of the same year, it was detected in eastern Washington. by July, the rust developed to severe disease intensities in southwestern Oregon and northern California. In 1996, barley stripe rust was widely destructive in California (causing a total loss of some fields) and was detected in both eastern and western Washington and Oregon. Since then, it has frequently caused significant damage whenever the weather is favorable for the disease. I expect that it will continue to be destructive if not controlled.

Based on past information about wheat stripe rust in this region, barley stripe rust in this and other regions, and controlled temperature tests in the greenhouse, we have determined that the environment in the Pacific Northwest is highly favorable for the disease. Now that barley stripe rust has appeared in Oregon, Washington, and northern Idaho, it will remain in the region and spread throughout the Pacific Northwest. Field research in the Pacific Northwest was not appropriate until the disease became widespread. Now that the disease is in the region, both field and controlled environmental research will be needed to clearly understand how weather and management contribute to severe epidemics of the rust.

Monitoring the pathogen is important. To forewarn growers and breeders, we must determine prevalence, distribution, and severity of the disease, identify races; determine how races evolve; and determine vulnerability of cultivars to races. Barley stripe rusts and wheat stripe rust cannot be differentiated without extensive, detailed tests in the greenhouse. These include testing the cultures of the pathogen on a series of wheat and barley differential cultivars. To add to the difficulties, we determined that at least 31 races and probably more races of the barley stripe rust pathogen exist in North America. Therefore, the barley stripe rust pathogen is extremely variable and difficult to control. Until 1994, we did not know how similar or different barley and wheat stripe rust are or if they can cross with one another and make races that could be severe on both crops. We have shown that new molecular techniques such as Random Amplified Polymorphic DNA (RAPD) analyses, can differentiate barley stripe rust from wheat stripe rust, other rusts of wheat and barley, and stripe rust of bluegrass. These techniques as well as studies on pathogen virulence are useful to differentiate wheat and barley pathogens from one another.

Resistant cultivars are the preferred control. There is already a significant effort in searching for resistance to barley stripe rust. Barley germplasm is being evaluated in South America, Mexico, Texas, Colorado, Oregon, and Washington for resistance to the disease. We have identified sources of resistance and are conducting studies to determine what genes provide resistance. Most of the current barley cultivars grown in the United States are susceptible, and it will take a few years to incorporate some types of rust resistance into locally adapted cultivars. Also, new races may circumvent some of the types of rust resistance. We know little about the types of resistance to barley stripe rust or how durable the resistance may be. There appears to be types such as the high-temperature, adult plant resistance that is so effective in wheat and slow rusting resistance Therefore, various types of resistance must be identified and germplasm must be evaluated more thoroughly in order to be used to develop locally adapted, resistant cultivars.

Fungicides have potential for control of barley stripe rust. They might be used alone or in combination with resistance. However, their use must be economical and non-hazardous to the environment. Therefore, seed treatments and foliar fungicides must be evaluated under various integrated management systems to determine what fungicides are effective and how they may be used. Baytan seed treatments prevent early rust development but not development at later growth stages. Tilt, Folicur, and Quadris should be available for use as foliar sprays.

Some barley cultivars are susceptible to stem rust. Stem rust is characterized by red pustules on stems and leaves. Stem rust was severe in 1993 in fields that were planted late because it appears later in the growing season. The cool, wet weather of 1993 was highly favorable for stem rust. In 1997 and 1998, the barley crop matured early enough to escape severe stem rust. Resistant cultivars and foliar sprays are possible controls for stem rust.

What can we do to prevent a barley stripe rust epidemic?

Monitor your crop. The disease will continue to exist in Washington and other states in the PNW. The fall and winter weather was favorable for stripe rust. Winterkill of voluntary barley may reduce the disease. Cool wet spring weather provided conditions that were favorable for the disease. The same weather conditions are favorable for wheat stripe rust and barley stripe rust; therefore, one clue that barley stripe rusts might be present is the presence of wheat stripe rust on early winter wheat. . The barley stripe rust may not develop until late in the spring, when damage is less severe. Being forewarned is half of the battle against the disease.

Timely control is important. Fields should be examined frequently throughout the growing season. The rust will probably appear first on the lowest leaves of the biggest plants that survived the winter. It should appear first in southern Washington and adjacent barley growing areas of Oregon. First, look on the lowest leaves for small golden-yellow blotches with powdery spores. Later as the plants grow, look for small golden-yellow stripes. Contact your county agent, and verify that it is stripe rust. Barley and wheat stripe rust look alike. If it is stripe rust, send a sample of several diseased leaves to Roland F. Line, USDA - ARS Plant Pathologist, PO Box 646430, WSU, Pullman, WA 99164-6430 or call (509) 335-3755 to determine if it is barley stripe rust or wheat stripe rust on barley. Continue to monitor the field. If it begins to spread and becomes more severe, it is probably barley stripe rust.

Plant early in the spring. Early planting should enable the barley crop to get a head start on the disease. Stripe rust development at late stages of growth will cause less damage. The amount of rust that survives the winter is important because if little rusts survives, the disease will not develop until late in the season. Even though early planting is preferable, sometimes very late plantings may escape the disease if the months of June and July are very dry, but yield of the very late plantings will usually be lower. Also, if June and July are wet, late plantings are more vulnerable to stem rust.

Consider treatment of the barley seed with Baytan. Baytan controls early stripe rust development but will not control the disease throughout the season. Also, Baytan is more expensive than the other seed treatments. Be sure to use Baytan at the rate indicated on the label. Higher rates may delay emergence when seed is planted deep. Baytan has less value when rust develops at late stages of plant growth.

Consider using foliar fungicides. Foliar sprays are not necessary unless severe rust is expected. Best control should be before the rust develops on the upper leaves. Tilt, Folicur, and Quadris are systemic fungicides that may be available for use as sprays. Determine the economical cost and benefits before using the foliar fungicide.

Genetics of Wheat Resistance to Stripe Rust

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Stripe rust, caused by *Puccinia striiformis* f. sp. *tritici*, is one of the most important diseases of wheat in the world. In the United States, the disease is most destructive in the Pacific Northwest. The use of resistant cultivars is the most effective, economic, and environmentally safe method to control the disease. Two types of resistance are widely used: race-specific seedling resistance and durable, high temperature and adult-plant (HTAP) resistance, which is non-race specific. In the Pacific Northwest of the United States, most common-wheat cultivars that are currently grown have durable, HTAP resistance. HTAP resistance has been most effective for all types of wheat, except club wheat. Club wheat multi-line cultivars consisting of several lines with different genes for race-specific resistance are the most popular.

Inheritance of seedling resistance has been studied in 27 wheat varieties that include cultivars used to differentiate races of *P. striiformis* f. sp. *tritici* and cultivars grown in the Pacific Northwest. Resistant cultivars were crossed with susceptible cultivars to determine their inheritance of resistance. Seedlings of parents and F_1, F_2, and F_3 progeny were tested with different races under controlled greenhouse conditions. Cultivars Chinese 166, Lemhi, *Triticum spelta album*, Riebesel 47/51, Tyee, and Spaldings prolific each have a single gene for resistance. Heines VII, Heines Peko, Cappelle Desprez, Nord Desprez, Minister, Vilmorin 23, Hybrid 46, Heines Kolben, Fielder, Lee, Tres, Daws, Produra each have two genes for resistance. Druchamp, Stephens, Paha, Yamhill, and Carstens V each have three genes for seedling resistance. Diallel analysis was used to identify the genes. Pedigree and race reactions were also used to determine the same gene, allelic, or linked genes. As shown in Table 1, 43 genes were identified in these cultivars. Most of the genes were located using monosomic analysis.

HTAP resistance in Gaines, Nugaines, Luke, Druchamp, and Stephens was quantitatively inherited. The estimated numbers of loci controlling the resistance are listed in Table 2. The resistance in these cultivars was partially recessive. Additive component played a major role in the gene action of HTAP resistance. In addition, epistatic interactions were significant in some of the cultivars. Cytoplasmic effects were observed in Druchamp and Stephens.

Molecular techniques were used to develop markers for stripe rust resistance. A RAPD marker associated with quantitative trait loci for durable, HTAP resistance was identified using bulked segregant analysis of F3 families. Genomic DNAs of the five most resistant and five most susceptible F3 families of a cross between Stephens (resistant) and Michigan Amber (susceptible) were bulked based on disease severity ratings from field data. A 1.1 kb DNA fragment amplified by primer OPF-14 was present in the resistant bulked samples and Stephens, but not in the susceptible bulked samples and Michigan Amber. Sequence characterized amplified region (SCAR) primers developed from the RAPD marker were used to analyze the F_5 families. The specific PCR band was present in six of the top resistant F_5 families but not in the susceptible families. RFLP and nulli-tetrasomic analyses show that the marker is located on the short arm of chromosome 3B.

Table 1. Genes for seedling resistance to stripe rust and their chromosomal locations in wheat cultivars

Yr gene	Cultivar	Chromosomal location	Mode of inheritance[a]
Yr1	Chinese 166	2A	D
Yr2	Heines VII	7B	D/R
	Heines Peko	7B	D/R
	Yamhill	7B	D/R
Yr3a	Cappelle Desprez		D/R
	Nord Desprez	1B	D/R
	Druchamp	1B	D/R
	Stephens	1B	D/R
Yr3c	Minister	1B	D/R
Yr4a	Cappelle Desprez		D/R
	Vilmorin 23	6B	D/R
	Yamhill	6B	D/R
Yr4b	Hybrid 46	6B	D/R
Yr5	*T. spelta album*	2B	D
Yr6	Heines Kolben	7B	D/R
	Heines Peko	7B	D/R
	Fielder	7B	D/R
Yr8	Compair	2D	D
Yr9	Riebesel 47/51	1B (1R)	D
	Clement	1B (1R)	D
Yr10	Moro	1B	D
Yr19	Compair	5B	D/R
Yr20	Fielder	6D	D/R
Yr21	Lemhi	1B	D
Yr22	Lee	4D	D
Yr23	Lee	6D	D/R

Yr gene	Cultivar	Chromosomal location	Mode of inheritance[a]
YrHVII	Heines VII	4A	D/R
YrHK	Heines Kolben		D/R
YrCle	Clement	4B	D/R
YrMor	Moro	4B	D
YrTye	Tyee	6D	D/R
YrTr1	Tres	6D	D
YrTr2	Tres	3A	D/R
YrDa1	Daws	1A	D
YrDa2	Daws	5D	D/R
YrND	Nord Desprez	4A	D/R
YrDru	Druchamp	5B	D/R
YrDru2	Druchamp	6A	D
YrSte	Stephens	2B	D/R
YrSte2	Stephens	3B	D
YrMin	Minister	4A	D/R
YrH46	Hybrid 46	6A	D/R
YrV23	Vilmorin 23	2B	D/R
YrYam	Yamhill	4B	D/R
YrSP	Spaldings Prolific		D
YrPr1	Produra		R
YrPr2	Produra		R
YrPa1	Paha		D
YrPa2	Paha		R
YrPa3	Paha		R
YrCV1	Carstens V		D/R
YrCV2	Carstens V		D/R
YrCV3	Carstens V		D/R

[a] D = dominant, R = recessive, and D/R = either dominant or recessive depending upon the parent used in the cross and the race used in the test.

To increase the efficiency of marker development for disease resistance, we developed a molecular technique called resistance gene analog polymorphism (RGAP)[1]. Primers based on conserved regions of cloned resistance genes from different plant species were used to amplify genomic DNA of wheat. The amplified PCR products were resolved using denaturing polyacrylamide gel electrophoresis followed by silver staining. Depending upon primers, 20 to over 100 bands were detectable in wheat. As high as 11% polymorphism between Stephens and Michigan Amber was detected with certain primers. Using F_6 recombinant inbred lines from the Stephens X Michigan Amber cross, we found that most polymorphic bands amplified with primers based on leucine-rich repeats (LRR), nucleotide-binding sites (NBS), and protein kinase genes were inherited as a single locus. Linkages between RGAP markers and seedling resistance genes in Stephens were obtained. The F_8 recombinant inbred lines are used to develop RGAP markers associated with the quantitative trait loci for the durable HTAP resistance.

Wheat near-isogenic lines were used to develop molecular markers for stripe rust resistance genes using the RGAP technique. RGA primers were used to screen the recurrent parent (Avocet S) and NILs carrying single stripe rust resistance genes (*Yr1*, *Yr5*, *Yr7*, *Yr8*, *Yr9*, *Yr10*, *Yr15*, and *Yr17*). Genomic DNA of NILs, the recurrent parent (Avocet S), and *Yr* gene-carrying cultivars were amplified with primers based on LRR, NBS, and kinase domains of resistance genes. Amplified products were separated on denatured polyacrylamide gels and visualized using silver staining. At least one specific RGAP marker was detected for each NIL. For *Yr5*, *Yr8*, *Yr9*, and *Yr15*, which are resistant to all races of *P. striiformis* f. sp. *tritici* so far in the United States, 12, 27, 28, 18 specific RGAP markers were identified, respectively. The NILs were backcrossed to the susceptible recurrent parent to develop mapping populations for co-segregation analyses. Either BC_7:F_2 or BC_7:F_3 progeny were used to confirm the association of the specific markers to the *Yr* genes. So far, seven RGAP markers have been proven to be co-segregating or tightly linked to *Yr9*, one to *Yr5*, and one to *Yr15*. More than 200 seeds were obtained from the four-way cross, F1(Yr5 X Yr8) X F1(Yr9 X Yr15), for combining the four *Yr* genes using the RGAP markers.

Table 2. Genes for durable, high-temperature, adult-plant resistance to stripe rust in wheat cultivars

Cultivar	*Yr* gene	Mode of inheritance
Gaines	*YrA1*	Partially recessive
Nugaines	*YrA1*, *YrA2*	Partially recessive, additive, epistatic
Luke	*YrA3*, *YrA4*	Partially recessive, additive, epistatic
Druchamp	*YrA5*, *YrA6*	Partially recessive, additive, epistatic, cytoplasmic effect
Stephens	*YrA7*, *YrA8*	Partially recessive, additive, cytoplasmic effect

Reference:

[1] Chen, X.M., Line, R.F., and Leung, H. 1998. Genome scanning for resistance gene analogs in rice, barley, and wheat by high-resolution electrophoresis. Theor. Appl. Genet. 97:345-355.

Genetics of Resistance to Stripe Rust and Molecular Mapping of Disease Resistance Genes in Barley

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Stripe rust of barley, caused by *Puccinia striiformis* f. sp. *hordei* , was first observed in the Unites States in 1991 at Uvalde, Texas. Since then, the disease has been detected in Texas, Oklahoma, New Mexico, Arizona, Colorado, Utah, California, Idaho, Montana, Oregon, and Washington. The disease is firmly established in the U.S., especially California and the Pacific Northwest, where the environment is highly favorable for stripe rust. Because major cultivars grown in the region are susceptible, the disease has a high potential for causing major losses when not controlled. The use of resistant cultivars is the most economical method of controlling rusts on cereals. Barley genotypes Abyssinian 14, BBA 2890, Grannelose Zweizeilige, PI 548708, PI 548734, PI 548747, and Stauffers Obersulzer are resistant to all races of *Puccinia striiformis* f. sp. *hordei* identified in North America. Astrix, BBA 809, Bigo, Cambrinus, Emir, Heils Franken, Hiproly, I5, Mazurka, Trumpf, and Varunda have resistance to certain races. Topper and Steptoe are susceptible to all races. Seedlings of parents and F_1, F_2, and F_3 progeny from crosses of resistant genotypes with Topper and Steptoe were tested for resistance to North American *P. striiformis* f. sp. *hordei* races PSH-1, PSH-4, PSH-10, PSH-13, and PSH-20. When tested with PSH-1, one recessive gene was detected in BBA 809, BBA2890, Bigo, Hiproly, and Grannelose Zweizeilige; two recessive genes were detected in Emir, I5, PI 548708, PI 548734, PI 548747, Varunda, and Astrix; and one dominant gene and one recessive gene were detected in Abyssinian 14 and Stauffers Obersulzer. In tests with PSH-4, BBA 809 had one recessive gene; Trumpf had two recessive genes; and Astrix had two partially recessive genes. In tests with PSH-13, one recessive gene was detected in BBA 2890, Grannelose Zweizeilige, I5, and PI 548708, and two recessive genes were detected in Abyssinian 14, Hiproly, PI 548734, and PI 548747. When tested with PSH-20, Bigo had one recessive gene, and Heils Franken had a recessive gene and a dominant gene. A gene in Cambrinus for resistance to PSH-10 and a gene in Mazurka for resistance to PSH-20 were dominant based on the response of the first seedling leaf but recessive based on the response of the second leaf. Four different types of epistasis were detected. Information on the number of genes, mode of inheritance, and non-allelic gene interactions should be useful in understanding the host-pathogen interaction and in barley breeding for stripe rust resistance.

To determine what genes are in the genotypes and their relationships, all possible crosses among the 18 genotypes were made in a greenhouse. Seedlings of parents and F_2 progeny were tested under controlled conditions for resistance to selected races that were avirulent on both parents. Based on segregation of the diallel crosses and the responses of the progeny to the selected races, at least 26 of the 30 genes that were detected were uniquely different. The single genes in Bigo, Trumpf, Mazurka, and BBA 2890 and one of the genes in PI 548708, PI 548734, PI 548747, and Abyssinian 14 were linked. One of the two genes in PI 548734 was linked to one of the two genes in I 5. The single gene in Cambrinus and one of the genes in Heils Franken and Astrix were the same or closely linked. The single genes in Grannelose Zweizeilige and BBA 809 and the two genes in Stauffers Obersulzer, Emir, Hiproly, and Varunda were different from all other genes and different from each other. Various gene interactions were also observed.

Table 1. The *Rps* genes for resistance to *Puccinia striiformis* f. sp. *hordei* in barley genotypes

Gene[a]	***Barley genotype***	Races detecting the gene
rps1.a	BBA 2890, PI 548734	PSH-1, PSH-13
rps1.b	Bigo	PSH-1, PSH-10
rps1.c	Mazurka	PSH-1, PSH-10
rps2	Abed Binder 12[b]	not in this study
rps3	I 5	PSH-1, PSH-13
Rps4	Cambrinus, Heils Franken, Astrix	PSH-10
rps5	Heils Franken	PSH-10, PSH-20
rps6	Emir	PSH-1
rps7	Emir	PSH-1
rps8	Astrix	PSH-1, PSH-10
rps9	Hiproly	PSH-1, PSH-13
rps10	Hiproly	PSH-1
rps11	Varunda	PSH-1
rps12	Varunda	PSH-1
rps13	Trumpf	PSH-1, PSH-10
rps14	Trumpf	PSH-1, PSH-10
rps15	BBA 809	PSH-1, PSH-10
rps16	PI 548708	PSH-1, PSH-13
rps17	PI548708	PSH-1
rps18	PI 548734	PSH-1, PSH-13
rps19	PI 548747	PSH-1, PSH-13
rps20	PI 548747	PSH-1, PSH-13
rps21	Abyssinian 14	PSH-1, PSH-13
Rps22	Abyssinian 14	PSH-1, PSH-13
rps23	Grannelose Zweizeilige	PSH-1, PSH-13
rps24	I 5	PSH-1, PSH-13
rps25	Stauffers Obersulzer	PSH-1, PSH-13
Rps26	Stauffers Obersulzer	PSH-1, PSH-13

[a] *rps1*, *rps2*, *rps3*, and Rps4 were previously named *yr*, *yr2*, *yr3*, and *Yr4*, respectively (20,25)

Most recently, we developed a new technique for efficiently identifying molecular markers that are directly associated with resistance genes called resistance gene analog polymorphism (RGAP). In co-operation with Dr. Patrick Hayes at Oregon State University and Dr. Andris Kleinhofs at WSU, we have mapped several genes for resistance to stripe rust, leaf rust (*P. hordei*), scald (*Phynchosporium secalis*), barley yellow dwarf (BYDV), and net blotch (*Pyrenophora teres*) in the double-haploid population of Shyri X Galena using RGAP markers, in combination with AFLP, SSR, and RFLP markers. Quantitative trait loci (QTL) and major genes were identified on chromosomes 2, 3, 5, and 6 for stripe rust resistance; chromosome 1 for leaf rust resistance; chromosomes 1, 3, 4, and 5 for BYDV resistance; chromosomes 3 and 6 for net blotch resistance; and chromosomes 1 and 3 for scald resistance. Of 144 RGAP markers, 23 were co-dominant with or tightly linked to other RGAP markers. The remaining121 RGAP markers that represented different loci were used to saturate the seven linkage groups constructed with 36 RFLP, 35 SSR, and 16 AFLP markers. One hundred and ten of the 121 RGAP markers were mapped on all seven chromosomes. RGAP markers were either coincident or tightly linked to QTL for stripe rust resistance on chromosomes 2 and 5, for scald resistance on chromosomes 1 and 3, for BYDV resistance on chromosome 1, and for net blotch resistance on chromosome 3. RGAP markers were more closely linked to most of the other QTL than RFLP, AFLP, and SSR markers. The coincident markers should be useful in marker-assisted selection for breeding barley cultivars with resistance to these diseases and in cloning multiple disease resistance genes.

Doubled haploid lines of Gobernadora X CMB 643 were evaluated in Mexican fields for resistance to stripe rust, leaf rust, and scab. In addition, scab resistance was evaluated in China; London, UK; and North Dakota. RGAP and RFLP markers were used to map the resistance genes. Quantitative trait loci for stripe rust resistance were mapped on chromosomes 2, 3, 4, and 7. A single gene or a cluster of genes for resistance to leaf rust was mapped on chromosome 1. Resistance genes for scab resistance were mapped on chromosomes 1, 2, 3, 4, and 5. Coincident or tightly linked markers were detected for some of the disease resistance QTL. These markers should be useful in breeding barley cultivars with resistance to stripe rust, leaf rust, and scab.

MoreCrop 2.0: An Expert System for Managing Diseases of Wheat in the PNW

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Abstract: An information technology system for managing diseases of wheat was developed for the Pacific Northwest (PNW). The program is referred to by the acronym MoreCrop (Managerial Options for Reasonable Economical Control of Rusts and Other Pathogens) and is designed to predict diseases and provide managerial options in agronomic zones of the PNW. MoreCrop uses the classical disease triangle as the overriding principle in predicting a disease outcome. This means that a susceptible host, a virulent pathogen, and favorable environmental conditions must exist for the disease to develop and cause damage to the crop. MoreCrop predicts diseases and provides information, options, and suggestions for making decisions regarding management of wheat diseases based on geographical regions, agronomic zones, crop managerial practices, cultivar characteristics, field and disease history, and prevailing weather. MoreCrop can use past managerial decisions to reconstruct disease conditions, help you decide what disease control option to select, and provide disease and cultivar-related information for research, extension, and education. MoreCrop is a powerful teaching system; it can be used as an educational tool for understanding the epidemiology and control of wheat diseases. MoreCrop can analyze a predefined crop managerial scenario, test a customized disease control program; serve as a training and reference tool to solve real-time problems; and serve as a prototype in developing a total crop managerial program for wheat. MoreCrop is constantly updated and expanded to include new information on agronomic zones, diseases, wheat cultivars and their disease resistance characteristics, seed treatment and foliar sprays, and to utilize new computer technology. **MoreCrop is now freely available by download from http://pnw-ag.wsu.edu/morecrop/.**

History: The MoreCrop expert system for managing diseases of wheat in the Pacific Northwest, was developed by Roland F. Line and Ramon M. Cu, USDA-ARS, Wheat Genetics, Physiology, and Disease Research Unit, WSU in Pullman, Washington. Development of the system started in 1991 as an expansion of earlier guidelines for integrated control of rusts and other diseases, and it is based on more than 30 years of experience and research data by R.F. Line on crop management, epidemiology, and control of rusts, smuts, and other diseases. Information from other plant pathologists and crop scientists was also utilized. R.M. Cu utilized the existing knowledge on artificial intelligence and expert systems to develop the computer. The acronym MoreCrop (Managerial Options for Reasonable Economical Control of Rusts and Other Pathogens) was carefully selected for the meaning of the words. MoreCrop was distributed to the wheat growers and crop advisers in the PNW in August 1993 through the WSU Cooperative Extension Office as Extension Bulletin MCP0022. A full description of the concept and use of MoreCrop was published by the American Phytopathological Society in the journal Plant Disease (R.M. Cu and R.F. Line. 1994. An expert advisory system for wheat disease management. Plant Dis. 78:209-215). MoreCrop was featured in the Information Technology Workshop during the 6th International Congress of Plant Pathology, Montréal, Canada in 1993. The system was demonstrated at American Phytopathological Society workshops and integrated management meetings and was tested by numerous advisory experts and wheat specialists.

MoreCrop changes: Changes in hardware and software from 1993 to 1998 provided an opportunity to upgrade MoreCrop utilizing new computer technology. MoreCrop version 2.0 was released in March 1999. The new version was made flexible with a new capability. The new features included are enhancement in the crop managerial selection, improvement in data management of cultivars, an increase in the number of possible diseases (an increase from 16 to 30 diseases), incorporation of high-resolution images of diseases, and high flexibility in changing the use of fungicides. New wheat classes and new cultivars are included in the program. A powerful database is infused to hold cultivar information. Data on cultivar characteristics can be easily updated, and an infinite number of cultivars can be included in the program.

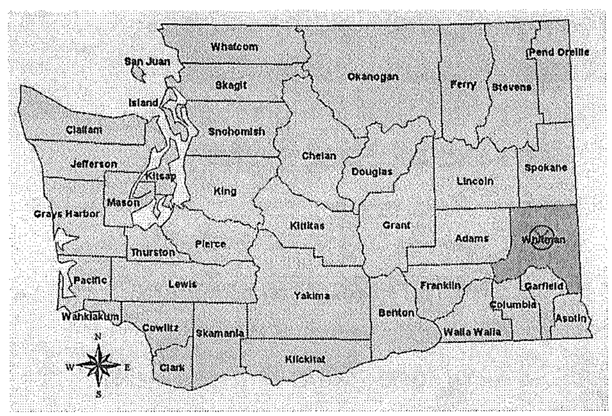
Adding specific rotational options has enhanced the crop rotation section. Planting dates have been linked to calendar dates, and a planting depth option is included. A powerful database was infused to hold cultivar information. Update of cultivar information can be done within the MoreCrop system, and inclusion or deletion of cultivars can easily be done. The disease outcome has been expanded to include 30 diseases (previously there were 16 diseases). The disease control suggestion is also expanded so that the inference engine could search from an array of more than a billion possible disease combinations. High-resolution images of wheat diseases are included and linked to every disease outcome. These images are easily available with a click of a mouse. The same images are also available in the library menu. The pattern for use of fungicides has been made flexible by allowing users to define or redefine the spectrum of fungicide efficacy and the timing of fungicide applications. Label restrictions on any fungicide can also be modified. Newly registered fungicides or fungicides with an emergency label can be included in the customized disease control program.

Cropping Systems Research: The Cunningham Farm

—Developing principles and strategies fundamental to reducing risks, increasing profits and improving environmental quality

Increased world competitiveness, the phase-out of government support programs, and growing concerns for air, soil, and water quality are stimulating a re-evaluation of crop rotation and tillage systems for wheat, barley, and other crops in the Inland Northwest. The Cunningham Farm cropping systems project is a new project and one of a network of cropping systems projects underway or planned for eastern Washington and adjacent northern Idaho and northeastern Oregon to provide the knowledge and technology needed by growers to reduce inputs and increase crop diversity while protecting the soil resource. Building research capacity for competitive cropping systems requires the combined experience, expertise, and resources of growers, researchers, industry, and agency people of the region. The project is therefore grounded in the premise that coordination and implementation of team efforts will lead to creative solutions not imagined by more singular efforts.

OVERVIEW: WSU's Cunningham Farm



Located in Whitman County, five miles Northeast of Pullman, the 140-acre Cunningham Farm includes soils and topography representative of the annual cropping region. A group of some 14 WSU and 8 USDA-ARS researchers is currently working to develop and implement a coordinated cropping systems project designed to meet the needs of growers specifically in this higher precipitation region of the Inland Northwest. Guided by an Advisory Committee comprised of a diverse constituency, the research conducted at the Cunningham Farm will strive to develop new guiding principles and practices fundamental to reducing risks, increasing profits, and improving environmental quality through direct-seeded cropping systems.

SCOPE

The Cunningham Farm project will serve some 2.6 million acres in Washington and 1 million acres in Idaho, representing the higher-precipitation areas where:

- annual cropping has long been practiced;
- spring and winter crops may be grown and opportunities exist to develop greater rotation diversity;
- the majority of growers continue to depend on intensive, tillage; and
- there exists great resource variability and the potential to intensively manage differing landscape features in diverse ways while enhancing the competitive advantage of the region.

CURRENT OBJECTIVES OF THE CUNNINGHAM FARM PROJECT

1) To obtain baseline data and develop detailed histories and maps of yield, weed, pathogen, fertility, and other variables/features as a basis for (a) planning and implementing a comprehensive, direct-seed cropping-systems project and (b) provide a resource to attract and compete for diverse sources of outside funding.

2) To acquire and organize personnel, equipment, and funding sources needed to plan, implement, review, and maintain this comprehensive, direct-seed cropping systems project.

3) To establish specific cropping systems experiments within a total agricultural landscape management system.

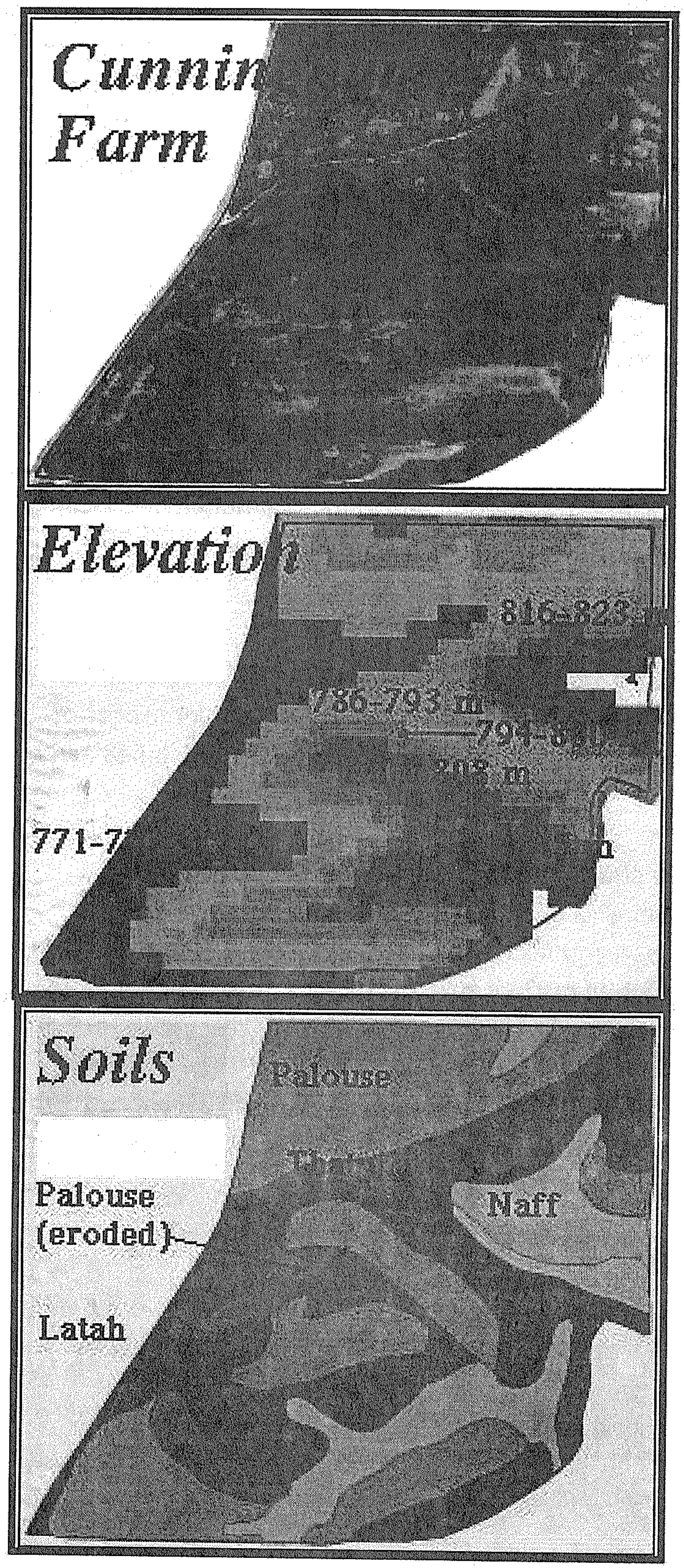


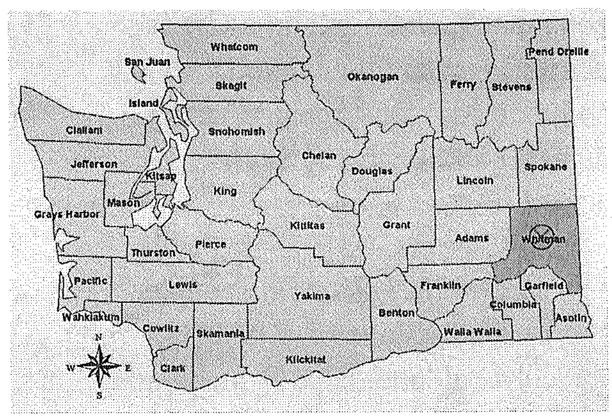
Photo taken in July 1996 (top). The border is our area of interest, 66.5 ha. The elevation map (middle) shows the general topography of the site. Soils at the site (bottom) include Palouse (45%), Thatuna (35%), and Naff Silt Loams (20%).

Cropping Systems Research: The Cunningham Farm

—Developing principles and strategies fundamental to reducing risks, increasing profits and improving environmental quality

Increased world competitiveness, the phase-out of government support programs, and growing concerns for air, soil, and water quality are stimulating a re-evaluation of crop rotation and tillage systems for wheat, barley, and other crops in the Inland Northwest. The Cunningham Farm cropping systems project is a new project and one of a network of cropping systems projects underway or planned for eastern Washington and adjacent northern Idaho and northeastern Oregon to provide the knowledge and technology needed by growers to reduce inputs and increase crop diversity while protecting the soil resource. Building research capacity for competitive cropping systems requires the combined experience, expertise, and resources of growers, researchers, industry, and agency people of the region. The project is therefore grounded in the premise that coordination and implementation of team efforts will lead to creative solutions not imagined by more singular efforts.

OVERVIEW: WSU's Cunningham Farm



Located in Whitman County, five miles Northeast of Pullman, the 140-acre Cunningham Farm includes soils and topography representative of the annual cropping region. A group of some 14 WSU and 8 USDA-ARS researchers is currently working to develop and implement a coordinated cropping systems project designed to meet the needs of growers specifically in this higher precipitation region of the Inland Northwest. Guided by an Advisory Committee comprised of a diverse constituency, the research conducted at the Cunningham Farm will strive to develop new guiding principles and practices fundamental to reducing risks, increasing profits, and improving environmental quality through direct-seeded cropping systems.

SCOPE

The Cunningham Farm project will serve some 2.6 million acres in Washington and 1 million acres in Idaho, representing the higher-precipitation areas where:

- annual cropping has long been practiced;
- spring and winter crops may be grown and opportunities exist to develop greater rotation diversity;
- the majority of growers continue to depend on intensive, tillage; and
- there exists great resource variability and the potential to intensively manage differing landscape features in diverse ways while enhancing the competitive advantage of the region.

CURRENT OBJECTIVES OF THE CUNNINGHAM FARM PROJECT

1) To obtain baseline data and develop detailed histories and maps of yield, weed, pathogen, fertility, and other variables/features as a basis for (a) planning and implementing a comprehensive, direct-seed cropping-systems project and (b) provide a resource to attract and compete for diverse sources of outside funding.

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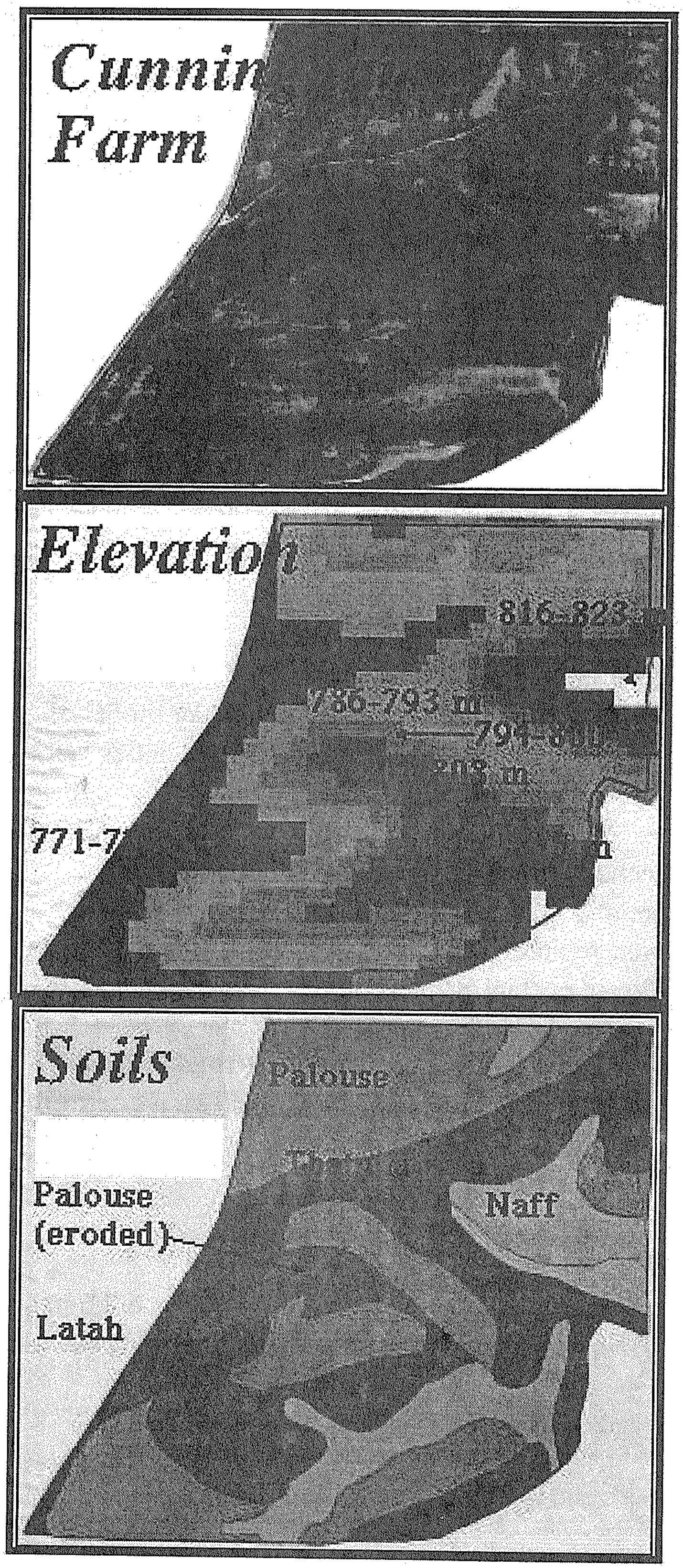

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Organizational chart for the WSU Cunningham Farm.

WSU Cunningham Farm Advisory Committee

- Growers
- Research Farm Managers
- Federal and State Agency Representatives
- WSU Extension
- Researchers
- Commodity Commission Representatives
- Industry Representatives
- Regional Environmental Organization Representatives

Management and Field Operations

- R. James Cook
- Eric R. Gallandt
- David R. Huggins
- Ron Sloot
- Aaron Davis

Technical/Research

- Remote Sensing
- Erosion Control
- Soil Science and Hydrology
- Soil Borne Diseases
- Soil Microbiology/Soil Quality
- Plant Breeding and Variety Testing
- Weed Science
- Production Economics

Outreach/Extension

- Roger J. Veseth
- Joseph P. Yenish
- Timothy E. Fiez

Accomplishments (9/98 - 4/99)

- Assumed responsibility for management of the approximately 140 acres of WSU-owned land known as the "Cunningham farm," which is the land dedicated to this direct-seed cropping systems study.

- Identified an Advisory Committee consisting of growers, field managers, agency representatives, extension, researchers, commodity organizations and local agribusiness, and representatives of regional environmental groups.

- Established a farm management "crew" and began the process of obtaining equipment, including, thus far, a three-point hitch sprayer for large plots (for use on existing, new 70 hp JD tractor), a 5-row no-till planter for small plots, a 15-foot prototype Great Plains no-till drill provided for this first year at no cost to the project, and a used International 2-ton grain truck with a new grain auger.

- Acquired high-resolution orthophotos of the site and collected a series of aerial photographs that have been geo-referenced and used to establish the base layer of a Geographic Information System for the Cunningham Farm. The GIS presently includes a digital orthophoto, soil series, and digital elevation model.

- Completed intensive soil sampling based on a non-aligned grid system for detailed analysis of soils, profile water, nutrient status, weed seed bank, and populations of soilborne pathogens; 369 separate locations were located by GPS and samples were collected.

- Completed a more limited but strategic soil sampling for available nitrogen in the spring of 1999 in the 5-foot profile, and then fertilized and direct-seeded the entire site to hard red spring wheat (WPB 926R) as one-pass into stubble of spring wheat harvested in 1998. Site-specific yields and protein contents of the grain will be determined and related to soil nitrogen supply using slope, aspect, and other physical features of the field as the source of site-variability.

The full cropping systems project will be designed over the course of the current "year 2" and implemented in year 3, which will commence in 2000. No tour is planned for this project in 1999, but anyone wishing to visit this site or learn more about the project should contact any one of the three individuals named below.

Contact Information

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DIRECT-SEED CASE STUDY SERIES

Grower Experiences with Direct-Seed Cropping Systems in the Inland Northwest

Ellen Mallory, Tim Fiez, Roger Veseth, Dennis Roe and Donald Wysocki

Veteran PNW direct-seeders will share their experiences and knowledge in an upcoming series of case studies, to be published as Pacific Northwest Extension bulletins. Shown here are preliminary printings of the Rea and Aeschliman case studies for the 1999 Direct-Seed Cropping Systems Conference.

Why a Direct-Seed Case Study Series?

Many established direct-seeders say one of the keys to their success was having other direct-seeders share their experience and knowledge with them as they developed their own system. This series of seventeen case studies will allow you to learn from experienced direct-seeders throughout the Inland Northwest. Each case study features a single farm operation and will contain:

- How the grower(s) became interested in and started direct-seeding.
- Lessons they have learned.
- Description of their current direct-seed system including:
  - Crops and Rotation
  - Residue management
  - Pest management
  - Fertility program
  - Seeding strategy
- Description and evaluation of the drill(s) they are using.
- Primary benefits and challenges of direct-seeding seen by the growers.
- Advice for new direct-seeders.
- Economic summary (when available).

Who will the Case Studies feature?

The cases are distributed over the range of rainfall zones in the wheat-producing areas of Washington, Idaho, and Oregon. They also cover a variety of no-till drills and cropping systems. Twelve of the seventeen cases are almost ready for publication; they profile the following growers:

Grower(s)	County	State
John and Cory Aeschliman	Whitman	WA
Pat Barker and Steve Shoun	Columbia	WA
Jack and Mike Ensley	Whitman	WA
Frank Lange	Whitman	WA
Frank Mader and Tim Rust	Umatilla	OR
Tim, Kevin and Kurt Melville	Wallowa	OR
John Rea	WallaWalla	WA
Nathan and Steve Riggers	Lewis	ID
Art Schultheis	Whitman	WA
Sam Seale	Gilliam	OR
Mike Sr. and Mike Jr. Thomas	WallaWalla	WA
Paul Williams	Lincoln	WA

What kind of advice will be offered in the Direct-Seed Case Studies?

The case studies rely heavily on the farmer's own words. Below is a sampling of their advice.

"Take a piece of land, what ever you think you can afford to try it on, say 50 or 100 acres, get it into a rotation in a direct-seed system, and give it a try. But do things right. Make sure you have your green bridge taken care of. Manage your residue. Seed the correct depth. Do all of those things and don't judge it after just one pass. Do it for five years on the same piece of ground and then you will start seeing some of the benefits." – Pat Barker

"Don't cut short on your rotation--that'll provide you a big safety margin against having something go wrong as far as disease or weeds." – Nathan Riggers (3-year rotation: winter wheat/spring wheat/legume or canola)

"Pay attention to the 'green bridge.' Get the green volunteer and weeds dead 2 to 3 weeks prior to planting. Don't be fooled, the pathogens are there waiting for the new plant to start so they can hop on and ride for another year." – John Aeschliman

"The number one challenge is getting good seed-to-soil contact in heavy residue to get a good stand." – Tim Melville

"When you're seeding you've got to be down there, you've got to be looking at that stuff. Every day, every time you move to a new piece, it's a new thing, you've got to change your drill so it works." – John Rea

"The timing is more critical with no-till than it is with conventional. You've got a smaller hammer [with herbicides vs. tillage] and you've got to hit it just perfect. Those guys [conventional-tillage farmers] have a big hammer and they've got two weeks either side of ideal to hit it." – Frank Lange

"One thing about this kind of farming, it's hard to impress the neighbors because it's not what they are used to seeing. A lot of times when they drive by a field and it looks kind of rugged, they form adverse opinions of how that field is being managed. But you have to wait until all of the scorecards come in to really pass judgement." – Mike Ensley

"Don't try to reinvent the wheel. If someone in your area is successfully direct seeding, do what he does for awhile. Tap into what other direct-seeders have already learned. There's no use repeating the same mistakes they made. Then, when you get your feet firmly on the ground, you can branch off and do what you want to do." – Pat Barker

"Just go out and do it." – Nathan Riggers

How do you get the case studies?

Direct-Seed Case Studies will be available by the fall of 1999 through the Cooperative Extension bulletins offices in Washington, Idaho and Oregon. Contact WSU Cooperative Extension Publications at (509) 335-2857.

Maintenance of Surface Residues and N Fertility in Soft White Winter Wheat-Fallow vs. Continuous Hard Red Spring Wheat Cropping

F. L. Young, W. L Pan, K. K. Kidwell,
M. Thorne, M. Moneymaker, L. McGrew, J. Morse

The integrated spring wheat cropping trial at Ralston, WA continues to provide us with useful and interesting information on the potential benefits and constraints in moving towards no-till spring cropping in the intermediate rainfall zone of eastern Washington. The long-term experiment is designed to develop alternatives to winter wheat-fallow for improving the economic and environmental viability of wheat-based cropping systems. This multidisciplinary project involves scientists from USDA ARS, Washington State University, University of Idaho and Oregon State University. Support for this project has been provided by the WA Wheat Commission, WA Department of Ecology and USDA CSREES, STEEP III.

Grain Yield and Protein

The 1998-99 growing season concluded the first three years of the no-till spring cropping system project at Ralston, WA. The first year (1995-96) was the established year and the next two years (1996-97, 1997-98) represent one complete crop rotation cycle. Growing season precipitation was 14.0, 16.8, and 12.9 inches respectively. Crop yields reflect the above average annual precipitation.

Even with a moderate population of downy brome, 'Lewjain' winter wheat yielded 68 bu/A in 1998 with a test weight >60 lbs. Yield may have been limited by an apparent loss of N. 'Alpowa' spring wheat no-tilled into standing chem fallow stubble yielded 58 bu/A which was an increase of 3 bu/A compared to 1997. In 1998, continuous no-till HRSW yielded 37 bu/A (13 less than in 1997) but protein content was 15.7%, an increase of over 2% compared to the protein in 1997. However, one does not receive extra premium for any percentage over 15%. The no-till HRSW 'Butte86' alternating with barley 'Baroness' yielded very well (40 bu/A) in 1998 and also "made" protein at 14.4%. No-till spring barley yielded 1.51 T/A even though it had the highest incidence of Rhizoctonia compared to other treatments. Yield improved compared to the barley yield in 1996, the last time barley was planted in these same plots (east field). The pathogen effect on yield was lessened in 1998 because of improved management practices. These practices included increased seed rate from 55 to 65 lbs/A, increased N from 40 to 50 lbs/A, and increased P_2O_5 from 30 to 40 lbs/A.

Crop Residues for Erosion Protection

The following is a subset of data from the past two years illustrating the contrast in surface residues and N cycling in two cropping systems: winter wheat-conventional fallow and continuous no-till hard red spring wheat.

- The residue and crop cover in the conventional winter wheat fallow system is much more cyclical, while the cover in the continuous NT hard red spring wheat is maintained throughout the season (Fig. 1).

- For the fallow systems, crop residue is highest during the winter following wheat harvest (>90%), but dropped by nearly 50% after disking, undercutting and shank-fertilization. One subsequent rodweeding did not further decrease surface cover, maintaining it above 40%, but by the end of August of the fallow season, surface cover dropped to 21% while chemical fallow following spring wheat was maintained at 57%.
- All of the continuous spring cereals rotations behaved similarly, and overall trends are represented by the HRSW (Figure 1). The spring wheat residue in March covered 70% of the ground, and by late May, the residue had decomposed to 32% but the green plants added 28% cover to the system. At harvest, 70% residue cover was again achieved.

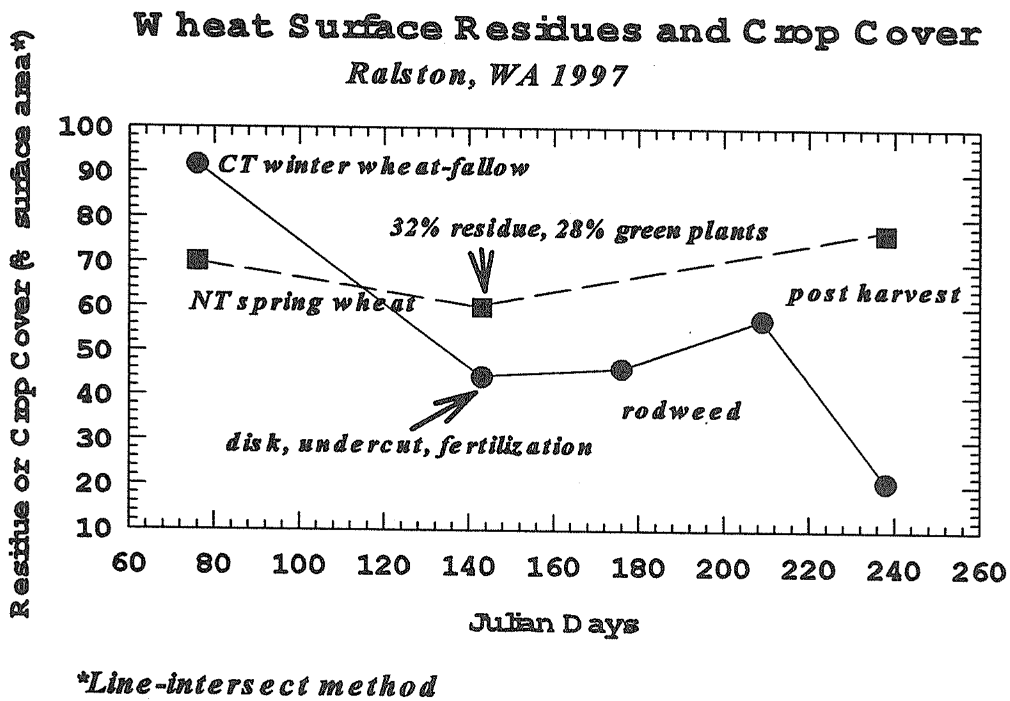

Figure 1. Seasonal trends in soil surface coverage from wheat residue and green plants in WW-F and continuous NT HRSW at Ralston, WA in 1997.

Nitrogen Fertilization and Cycling

- A buildup of 217 lb inorganic N/a in the 6 ft profile was observed on August 28, 1997 (Figs. 2 and 3) as a result of fertilization of summer fallow with 71 lb N/a and organic matter mineralization. After seeding winter wheat, a substantial reduction to 77 lb available N/a was observed on February 11, 1998. The apparent depletion of 154 lb N/a cannot be accounted for by plant uptake, since the wheat was still at the tillering stage at this time, and the bulk of N uptake had yet to occur. We estimate that the crop absorbed ~25 lb N/a by that stage, leaving an unaccounted 130 lb N/a. Possible pathways include leaching, denitrification, or immobilization. The profile distribution of nitrate suggests leaching was not a major pathway, since there was no increase in nitrate in the deeper depths. The apparent loss resulted in N deficient wheat by anthesis, as evidenced by yellowing leaves. A diagnostic survey taken at that time revealed low N concentration in the leaves, and virtually ***no*** available N remaining in the 6 ft profile. The mode of apparent N loss needs to be further investigated.

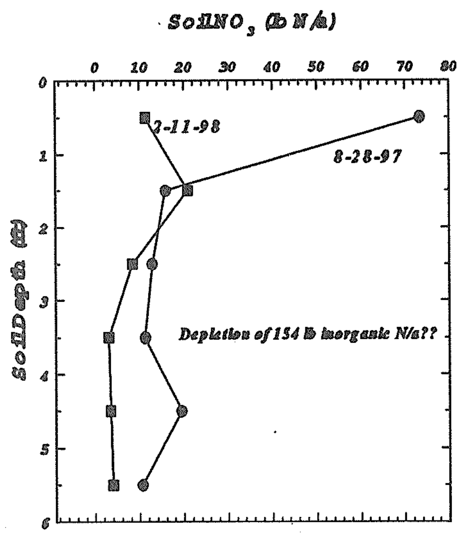

Figure 2. Soil nitrate in winter wheat after summer fallow at Ralston, WA.

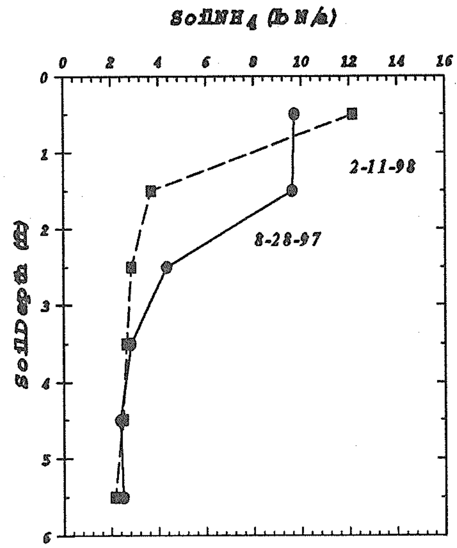

Figure 3. Soil ammonium in winter wheat after summer fallow at Ralston, WA.

- Residual nitrate (15 to 28 lb N/a) was present in the surface foot of soil at the end of the 1997 and 1998 growing seasons of continuous NT-HRSW, demonstrating that shallow N can be stranded in the surface soil when soil water is depleted from top to bottom and there is little in-season precipitation (Fig. 4).
- Residual nitrate (10 to 15 lb N/a) in the 6th ft suggests HRSW only effectively extracted N to 5 ft.
- Fertilization with 65 lb N/a in October 1997 increased soil ammonium in the 1st foot by 40 lb N/a (Fig. 5) and nitrate increased in the 2nd and 3rd feet by 27 lb N/a (Fig. 4) by February 11, 1998, suggesting (1) there was little N loss over this period in this system, and (2) nitrification was slowed due to cool soil temperatures. N depletion as a result of plant uptake mainly occurred from the top 3 ft. It is crucial to position a major portion of available N in the 2nd and 3rd feet to optimize N availability in this system. Fall fertilization appears to achieve this goal. Subsequent HRSW yields were 35 bu/acre and >14% protein.

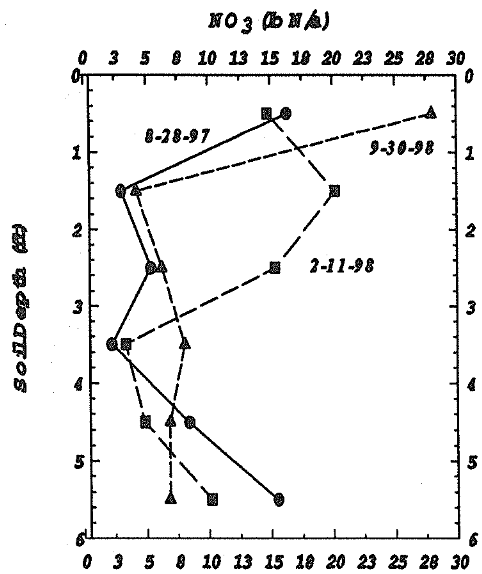

Figure 4. Soil nitrate in continuous hard red spring wheat at Ralston, WA.

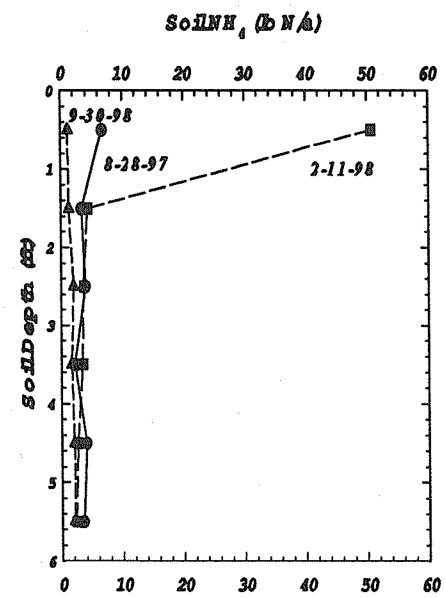

Figure 5. Soil ammonium in continuous hard red spring wheat at Ralston, WA.

Summary

Higher than average precipitation promoted competitive spring wheat yields. Continuous no-till spring cropping sustains surface crop residues more consistently throughout the cropping cycle compared to winter wheat fallow. Fall N fertilization provided deep N for mid-season availability required for HRSW protein production. The WSU spring wheat breeding program is developing cultivars with improved yield and protein performance for this agronomic zone.

Soil Is Alive!!

Ann C. Kennedy, USDA-ARS, Pullman, WA

The dry soil of summer, mud in spring and fall, and frozen soil in winter do not appear to be living, but soil is overflowing with life. A pinch of soil contains millions of tiny organisms critical to growing crops. A healthy soil, one full of active microorganisms, is essential to agriculture. Healthy soil produces healthy plants efficient in the accumulation of nutrients, weed control, and erosion control through extensive root systems. The key to healthy soil is the microbial population. The majority of soil microbes are beneficial to plant growth, but they need to be effectively managed, and to do that, we need to understand them better.

Soil is home to large numbers of many different types of microorganisms and macrofauna assembled in complex and diverse communities. The most common soil microorganisms are bacteria, actinomycetes, and fungi. These microorganisms are involved in organic residue decomposition and nutrient cycling. Actinomycetes produce compounds that give the rich, earthy smell of a newly plowed field. They are also key players in composting. Many actinomycetes produce antibiotics of the type we use when we are sick. Many fungi are plant pathogens; yet some form beneficial relationships with the root (mycorrhizae).

Macrofauna and microbes are nature's recyclers. When something dies (and even when it is living), the macrofauna and microbes use the plant material as food for their growth. Mites, earthworms and other macro fauna break the big pieces of residue into smaller pieces. Microbes break down the large compounds in the organic residue and change them into simpler, smaller compounds. This recycling into simpler compounds provides food for other microbes, macro-organisms and plants. Organic matter improves soil physical properties, increases water holding capacity, increases nutrient availability and acts as a cementing agent for holding soil particles together. Organic matter can be maintained by incorporation of crop residues, crop rotation, and addition of animal and green manures when possible. Addition of organic matter ensures a productive soil and stimulates plant growth by providing food for microorganisms. Organic matter also helps water infiltrate quickly allowing more water to flow into the soil than to flow across the surface and away.

Microorganisms help in the weathering process of soil minerals by the mobilization and solubilization of plant nutrients. Microorganisms can alter nutrient solubility making otherwise unavailable nutrients available to the plant by production of organic acids or by microbial uptake. The nutrient cycling processes controlled by microorganisms are affected by tillage and residue management.

The plant root feeds some of the organisms in the soil. The root leaks rich carbon compounds as food for the organisms. The area around the root then is full of intense microbial and macrofaunal activity. So often many of these microbial processes are carried out right near the root.

The symbiotic relationship between bacteria and legumes is one of the most widely studied and used plant-microbial interactions. Rhizobia, the bacteria, form nodules on the roots of the legume plant, take N_2 from the air and transform it into plant-available nitrogen. The plant provides a safe home and food for the bacteria, while the bacteria give the plant the nitrogen it needs. Inoculation of legumes with rhizobia can help add nitrogen to the soil.

Mycorrhizal fungi form symbiotic associations with plant roots. They are involved in the nutrient cycling process. Mycorrhizal associations enhance nutrient uptake by plants and expand the volume of soil the root can explore especially in stressed environments (low nutrient low water). This relationship may allow some protection to plant roots from pathogens. Mycorrhizal associations are enhanced by crop rotation and management practices favoring minimum disturbance.

Microbes and macrofauna play a major role in the formation of good soil structure. Fungi and actinomycetes produce sticky hyphal threads that bind soil particles together. Slime produced by bacteria acts as glue to also hold soil particles together. Earthworms and other macro organisms produce casts, which are aggregates of smaller soil particles. This activity helps aggregate the soil that reduces erosion, allows for good water infiltration and maintains adequate aeration of the soil.

Microbes have the potential to be used in biological control, which is the suppression of one pest by introducing a natural antagonist. Biocontrol can be used to control insects, pathogens and weeds either by lowering the populations of the pests or by reducing a pest's impact. The microbes function as a direct delivery system for any natural 'pesticide' they produce. For example, there are bacteria and fungi that produce different types of antibiotics that can be used to control many plant pathogens. Inhibitory bacteria that suppress growth of grass weeds but do not adversely affect crop growth can be used to control weeds. We are working towards managing these types of organisms in the soil.

Soil microbes and macrofauna carry out many beneficial functions. Many of these activities center around the decomposition of organic residues and nutrient cycling. So what can growers do to improve conditions for microbe which will in turn benefit crop growth and yields? That is not an easy question to answer, but here are some possibilities that we have found from our research on the Palouse Conservation Field Station.

For healthy soil and soil macro and microorganisms:

1. Reduce tillage and soil disturbance
2. Add residue
3. Rotate crops
4. Maintain soil pH
5. Minimize fallow
6. Minimize compaction

If you are interested in trying some microbial products that may be on the market, remember these guidelines:

1. Follow handling guidelines and remember that the material is a live organism,
2. Understand the system and what the microbes can and cannot do,
3. Check field trial data,
4. Use test strips to ensure that it works on your own farm.

Soil microbes and macrofauna are working hard to help you produce your crops and keep your soil healthy and on your farm. We need to take care of them as well!

Do No-Till Peas Benefit From Starter Fertilizer Applications?

Tim Fiez

Introduction and Summary of Past Research Results

Growers do not commonly apply fertilizer to dry pea crops as past research trials have found little yield benefit from N, P, or S fertilizers. The 1972 Washington State University Extension Bulletin, E.M. 3379, *Dry Pea and Lentil Fertilization,* summarized four fertilizer studies conducted during the late 1960's. These studies examined: 1) band versus broadcast application of P and K on eroded hilltops, 2) starter fertilizer applications with the seed versus broadcast application, 3) N fertilization, and 4) large plot comparisons of starter fertilizers using a dual boot drill application. The study of P and K applications on eroded hilltops found no K response and a P response only when soil test P levels were in the 2 ppm range (sodium acetate extraction). The starter fertilizer trial applied the fertilizers with the seed. Peas are extremely sensitive to fertilizer salts and all applications of N or P with the seed decreased yields. A starter application of S (8 lb S/acre applied as $CaSO_4$) did not reduce germination but there was no positive effect on yield. The N fertilizer trial conducted at three locations in 1968 found that N applications decreased yields. Increased weed growth associated with the N applications was one of the reasons noted for the lower yields. Finally, the large plot test of starter fertilizers found a slight yield increase (100 lb/acre) from an application of 19 lb N/acre and 22 lb S/acre as compared to the control. However, no statistics are provided in the 1972 bulletin to assess the confidence in the yield differences. As a whole, the 1972 bulletin suggests that pea or lentil fertilization is not warranted except under very low soil P levels. The most recent summary of pea and lentil fertilizer requirements can be found in the University of Idaho Northern Idaho Fertilizer Guide for peas and lentils, CIS 448. This guide includes tables listing fertilizer needs by soil test levels.

This past research indicates that growers should expect little benefit from pea or lentil fertilization. However, changes over the last 30 years such as improved weed control and increasing interest in direct seeding of peas and lentils, has caused us to re-examine the issue of fertilizing peas, specifically, direct seeded peas. Starter fertilizer applications have been found to increase cereal yields in direct seed systems particularly when root diseases limit root interception of immobile soil elements such as P. The 1972 *Dry Pea and Lentil Fertilization* publication mentions grower and dealer reports of favorable responses to starter fertilizers in cold, wet springs although the research contained in the report found no benefit in one year of trials. Recent work by various agriculture industry personnel has also found some positive responses to pea fertilization. Thus, as part of a systems approach to developing direct seed systems for peas and lentils (Guy et al., 1998), we initiated studies in 1998 to determine if there are yield benefits from applying starter applications of N, P, and S at seeding time with direct seed drills.

New Pea Soil Fertility Experiments

Starter applications of N, P, and S were tested under tilled and no-till seeding systems at four locations during the 1998 growing season. All the fertility trials were conducted within grower's fields as part of a larger on-farm test of tillage system influence on pea yield and post pea harvest soil conservation. The location of the four fertility trials and the cooperating growers are listed in Table 1. Because of the on-farm nature of these trials, the tillage systems are not identical between sites but each site included a pure no-till treatment and a fall chisel or plow treatment.

Table 1. Grower cooperators, location, and tillage systems for the pea fertility experiments.

Grower	Location	Tillage Systems
Bob Garrett	Endicott, WA	Chisel Plow
		Notil
Richard Druffel	Pullman, WA	Disk Ripper
		Notil
Art Schultheis	Colton, WA	Disk Ripper
		Notil
Nate and Steve Riggers	Nez Perce, ID	Plow
		Disk
		Burn
		Notil

The fertility treatments consisted of starter (20 lb/acre) rates of N, P, and S in all possible combinations. In both the tilled and no-till plots, the fertilizers were band applied 2" directly below the seed at planting time. Experimental observations included plant stand, harvest yield, aboveground biomass at harvest (check and the N + P + S fertilizer treatment only), and 1000-seed weight (check and the N + P + S fertilizer treatment only).

Results and Discussion

Because we banded the fertilizers below the seed by approximately 2", we observed no stand reductions from the fertilizer applications, which had occurred in past studies. At all plot locations, the fertilized plots could be visually differentiated from the non-fertilized control plots. The fertilized plots seemed to have greater early growth and vigor. However, at the two sites analyzed so far, the Riggers and Schultheis sites, there were no significant yield responses to any fertilizer treatment, and the results were the same in pure no-till plots and in plots which were tilled prior to planting (Table 2).

The N+P+S treatment increased non-seed aboveground biomass ("the vine weight") at the Riggers site by 22% compared to the control without increasing seed yield while there was no increase in non-seed aboveground biomass at the Schultheis location. Weight per 1000 seeds was similar between the N+P+S and non-fertilized treatments at the Riggers and Schultheis sites. The observation that the vine biomass was increased 22% by the N+P+S treatment at the Riggers site yet yield and 1000-seed weight were not affected could be due to several factors. The greater vine growth might not have resulted in an increase in pod number or there was an increase in the number of pods but each pod set fewer peas.

Table 2. Dry pea yield as affected by combinations of N, P, and S fertilizer at 20 lb/ac.

Fertilizer Treatment	Pea Yield	
	Riggers: Craigmont, ID	Schultheis: Colton, WA
	lb/ac	
Check	1607	2266
Banded Check (no fertilizer)	1724	2200
N	1652	2312
P	1773	2232
S	1748	2223
N + P	1813	2237
N + S	1793	2227
P + S	1612	2144
N + P + S	1668	2076

Conclusions

Results from 1998 confirm previous studies that have found little benefit from starter fertilizer applications on peas. The pea fertility experiments are being repeated at two locations in 1999 to further examine this issue.

References

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Row Spacing Effects on No-till Spring Wheat and Barley Yields in the Low-Rainfall Cropping Zone

Tim Fiez and William Schillinger

Introduction

Among the many issues growers must consider when selecting a drill for direct seeding is seed row spacing. With conventional tillage, most cereals in the inland Pacific Northwest are planted at row spacings between 7" and 16". The narrow 7" spacing is common among single and double disc drills while the widest row spacings are found with deep furrow hoe drills. When considering row spacing for a direct seed drill, one should consider both "operational" and agronomic issues. As row spacing increases, there will be more room for straw to pass between the openers, there is more room to mount various row cleaning attachments and fertilizer openers, and there are fewer actual moving pieces and numbers of openers, hoses, and bearings. However, in terms of agronomic issues, at some point as row spacing increases, yield potential will drop, as the rows become far enough apart that the crop does not optimally utilize sunlight, water, and nutrients. Furthermore, if you try to maintain an equal seeding rate per acre, you must plant more seeds per foot of row as the row spacing increases. This results in increased plant to plant competition within a seed row, which reduces tillering in cereals. In addition to direct effects on the crop, a narrower row spacing will result in quicker and more complete canopy cover which will increase the crop's competitiveness with weeds and provide greater soil surface protection.

To help growers evaluate the tradeoffs between the operational and agronomic advantages of various row spacings, we initiated an experiment to determine the effect of row spacing on yield of direct-seeded spring wheat and barley. This report summarizes the first year (1998) of this experiment conducted at the Washington State University Dryland Research Station at Lind. This site receives an average annual precipitation of 9.5".

Experimental Procedure

An experiment was designed to test the effect of rows spaced 7.5", 9", 12", and 16", on the yield and yield components of Alpowa spring wheat and Baronesse spring barley. To ensure that we only tested the impact of row spacing, seeding rate, fertilizer rate, and fertilizer placement relative the plant row were kept constant across all row spacings. We used a research no-till drill that allowed us to change row spacing and always place the fertilizer band 2" directly below the seed row. All plots were sown at a 70 lb/acre seeding rate and were fertilized with 40 lb N, 5 lb P, and 5 lb S per acre applied as a dry blend at planting using a deep band fertilizer opener running directly in front of the seed opener. The openers for both seed and fertilizer where an offset double disc type which resulted in very low soil disturbance.

Experimental measurements included plant stand, yield components (heads per area, seeds per head, and weight per 1000 seeds), grain yield, grain test weight, and grain protein.

Results and Discussion

Even though we planted the same number of seeds across all row spacings, stand counts taken 25 days after seeding showed that plant stands were lower on an area basis in the 16" row spacing treatments (data not shown). On average, plant stands in the 16" row spacing treatments were 27% less for the barley and 36% less for spring wheat compared to the 7.5", 9", and 12" treatments. To plant the same number of seeds per area, there were 2.1 times as many seeds planted per foot of row in the 16" treatments compared to the 7.5" treatments. The resulting seedling-to-seedling competition may have reduced seedling survival.

Yield results (Figure 1) for both spring wheat and barley indicate that the 16" row spacing decreased yields compared to narrower row spacings. For spring wheat, yields were statistically equal for the 7.5", 9" and 12" spacings. However, for the barley, the 7.5" spacing produced 220 lb/acre and the 9" spacing produced 333 lb/acre greater yield than the 12" spacing.

Analysis of the yield component data shows a strong relationship between heads per area and yield in both the spring wheat and spring barley (Figure 2). The other two yield components, kernels per head and 1000 kernel weight did not vary significantly across row spacings and were not related to yield. Thus, it would appear that the loss of yield potential with increasing row spacing is due to the inability of the crop to maintain head numbers per area because of within row crowding. Our data agree with published research conducted in other low-rainfall dryland regions of the world, which show that head density is the most important yield component for cereals when extreme drought is not a factor.

Conclusions

The results presented in this paper are from the first year of a two-year experiment, and hence it is difficult to draw strong conclusions. However, there seems to be good evidence that a 16" row spacing is too wide to produce maximum yields of spring wheat or barley at the Lind location. Furthermore there is some evidence that Baronesse spring barley which produced greater tiller numbers per area than the Alpowa spring wheat is more sensitive to within row crowding and that tiller numbers per area were reduced by a 12" row spacing as compared to a 7.5 and 9" row spacing. Because of this, there appears to be a yield benefit from seeding Baronesse barley at the 7.5 or 9" row spacing at least in 1998.

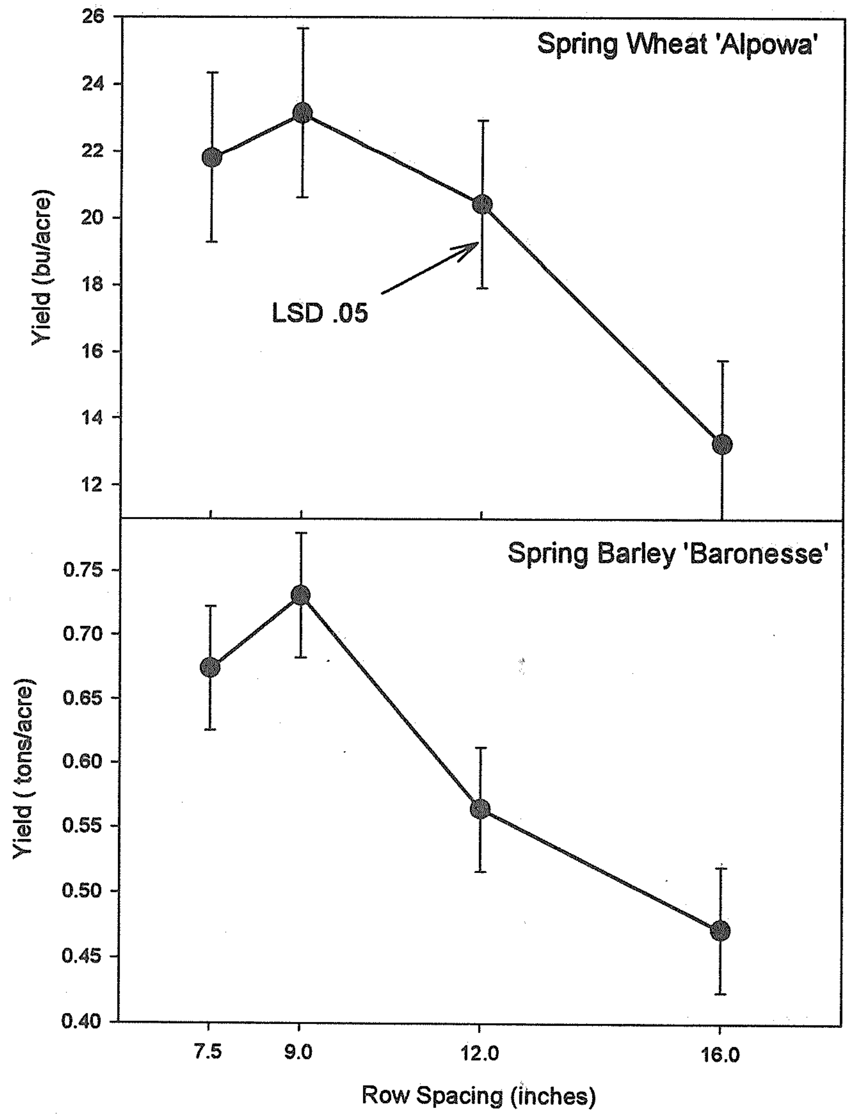

Figure 1. Yield of Alpowa spring wheat and Baronesse spring barley versus row spacing. Error bars represent the least significant difference at the 5% probability level.

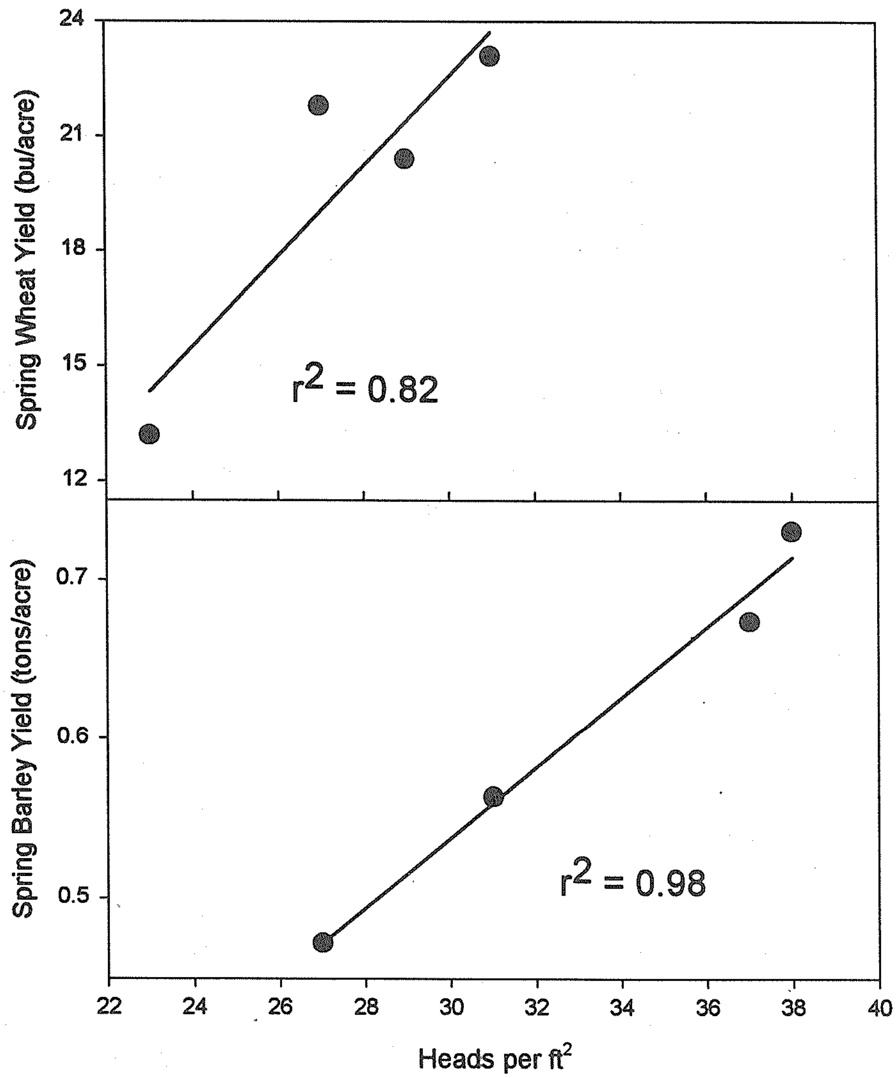

Figure 2. Yield of Alpowa spring wheat and Baronesse spring barley versus head number per ft^2.

Earthworm Dynamics and Soil Biology in Direct Seed (DS) Systems

D. F. Bezdicek, M. F. Fauci, and R. D. Roe

Crop residues accumulate at the soil surface in DS systems, but without tillage the recycling of nutrients is more dependent on the soil biota such as protozoa, nematodes and earthworms that ingest and recycle soil organic matter. Growers who spoke at the 1999 Direct Seed Conference in Spokane made numerous references to increased populations of earthworms under DS systems. They are very interested in earthworms because the worms have the ability to work their soil and improve soil structure and porosity. Most growers believe earthworms are indicators of good soil quality.

We began studying the population dynamics and species of earthworms at various locations in Eastern WA and Northern ID in 1998. We also initiated lab and field studies to determine how crop rotation and previous crop influenced earthworm populations. Studies are also underway to determine how DS and conventional systems differ in supporting bacteria, actinomycetes, fungi, protozoa, nematode, enchytraeid, and microarthropod populations. We have also begun several trials on the effectiveness of different lime application methods and rates on soil pH, microbial activity, and residue decomposition.

Earthworms were sampled in the long-term DS plots from our STEEP III study in the spring of 1998 and 1999. Earthworms were found at the Pullman, Palouse, Colfax, and Lewiston sites, but infrequently at the drier sites at St. John and Touchet. Other areas in Eastern WA and Northern ID were surveyed in the spring of 1999. The survey area is outlined in gray in the map below. Most worms were in the Apporectodea genus. These worms are geophagous which literally means "earth-eating". Their burrows are both horizontal and vertical.

Canadian research has shown increases in earthworm populations in response to different crop residues. More earthworms are found after a broadleaf crop in rotation, such as canola, mustard, flax, pea, and lentil. With the current interest in expanding crop rotation in the dryland region, we have an opportunity to study the differences in cereal and broadleaf residues on earthworm populations. Earthworm sampling rings were installed in November 1998 at the Ruark's plots near Pomeroy, WA. These plots are part of the NW Crop Rotation Project. We placed 8-inch diameter rings in plots representing each of the residues from the four-year rotation. We sampled twice in spring 1999 and plan to continue sampling over the next two seasons to follow the crop effect on earthworms. Preliminary results are shown in Figure 1. Laboratory studies also show better worm growth in soil amended with pea compared with wheat residues. The seasonal dynamics of earthworm populations at the UDSA Conservation Farm were studied at two landscape positions, an eroded sideslope and a bottomland position. Results are shown in Figure 2.

Growers can see earthworms. By studying and reporting on worm populations and the effect of management on them we can provide growers insight into the health of their soil. Our worm research complements our traditional STEEP III-funded research on soil quality where we measure soil microbial biomass and enzymes and other soil biology components that are not visible to the naked eye.

Map of area surveyed for earthworms in the spring of 1999 by Mary Fauci, Dave Bezdicek, and Darla Rugel. Agricultural fields were predominant area surveyed, although forest, pastures, and grasslands were also sampled in.

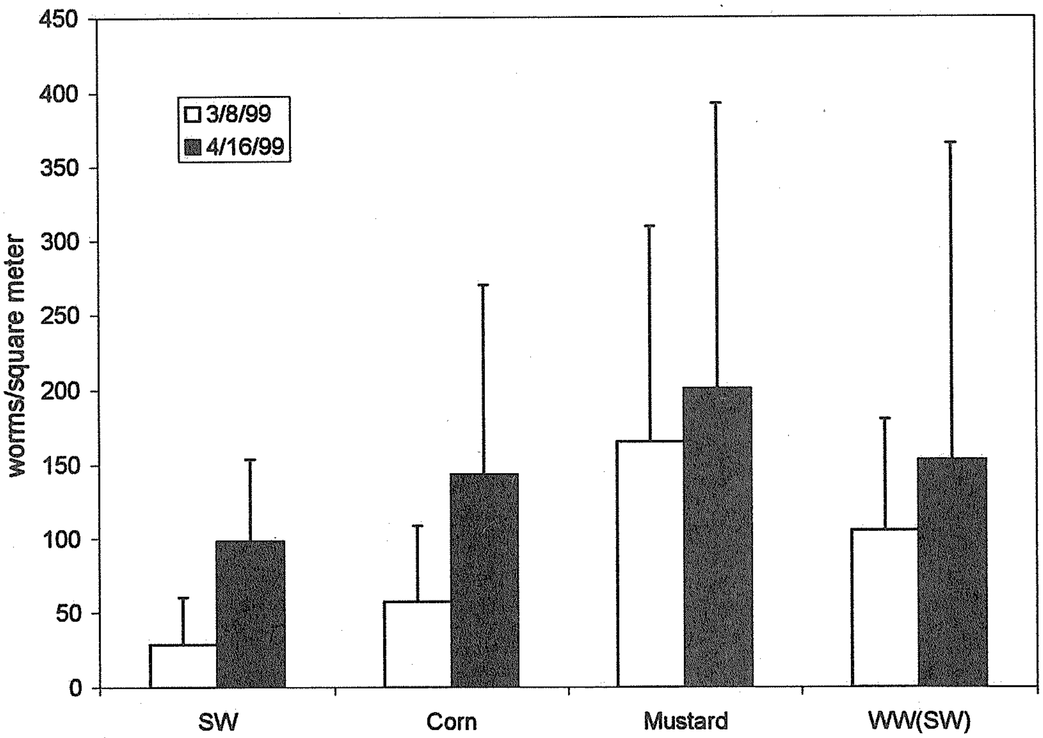

Figure 1. Worm populations in crop residues from the previous years crop at Ruark's NW Crops Project plots near Pomeroy, WA .

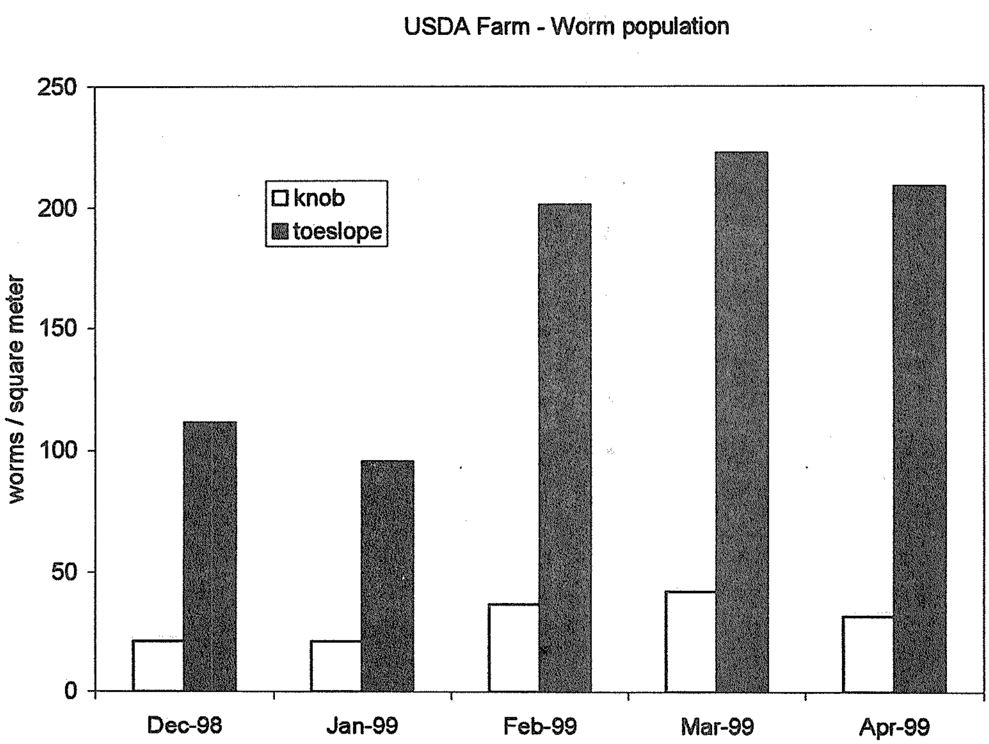

Figure 2. Worm populations at the USDA Conservation farm at two slope positions.

Impact of Long-Term Direct Seeding on Soil Quality

D. F. Bezdicek[1], J.P. Fuentes[1], J. Hammel[2], M. F. Fauci[1], R. D. Roe[3], and J. Mathison[1]
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Direct Seed (DS) agriculture presents some unique opportunities for reducing wind and water erosion and for improving crop productivity and economic returns. Reduction in tillage can increase soil organic matter and thereby increase soil quality. Many producers and researchers believe that soil quality improves under DS. Our goal is to document changes in soil quality attributed to DS agriculture. We have evaluated soil physical, chemical, and biological properties in cooperating grower fields in DS operation for 10 to 25 years in comparison to adjacent conventional practices (Table 1). Soil water storage, soil temperature and crop water use efficiency is also been monitored at two locations.

We followed soil quality changes attributed to DS agriculture in three agroclimatic zones in eastern Washington and northern Idaho by evaluating soil physical, chemical, and biological properties of long-term DS fields (Table 1). Most of the field results were reported in the 1997 STEEP III report. A summary of these results show that soil organic matter, microbial activity, soil N release, and soil test P and K were higher at all sites under DS compared to conventional tillage. The greatest increase in soil organic matter of 50% was noted at Palouse, with a slight increase noted at the wheat-fallow site at Touchet. Many of the above measurements were highest for DS compared to conventional at the soil surface 0-5 cm (0-2 inches), but were lower at the 5-20 cm depth due to the lack of surface soil inversion.

Water infiltration into soil is often higher under DS because surface residues facilitate infiltration into the soil, although the soil may be more compact from heavy equipment traffic. Ponded water infiltration shows that water entry is generally higher under DS than under conventional tillage (Table 2).

Surface impedance was generally higher under DS at the Palouse and Colfax that likely reflects the heavy no till drills used (1997 STEEP Report). We propose that DS systems may be more compact just below the soil surface, but that water infiltration may actually be enhanced due to the different soil pore size distribution. Under direct seed conditions, old root channels and earthworm channels are maintained from the lack of disturbance and this facilitates infiltration of water through more macro pores. How this affects water and nutrient movement should be studied as water movement and leaching of nutrients may be facilitated through macro pores.

In late 1997, weather stations were set up as part of Juan Pablo Fuentes's M.S work at the Palouse and Touchet sites to study winter soil water storage, seasonal changes in soil profile temperature and moisture, crop water use efficiency. The weather stations monitor total radiation, wind speed, air temperature, and soil temperature (seed zone at 5-cm depth). Soil nitrogen (ammonium and nitrate) is measured at monthly intervals to determine crop N use efficiency. Our results show that surface residues increased the water infiltration rate and suggest that there is greater potential for more storage of water under DS.

Total precipitation, total water consumed, crop yield, and crop water use efficiency for winter wheat at Palouse is shown in Table 3. Excellent yields were noted for both the DS and conventional fields. However, water use efficiency was higher under DS due to the higher yield obtained. Total water consumed was similar. Total precipitation, total water consumed, crop yield, and water use efficiency for DS spring barley and spring wheat under wheat-fallow at Touchet is shown in Table 3. Water use efficiency was higher under DS compared to wheat-fallow. Spring wheat was grown continuously for 14 years at the DS site, but replaced with spring barley in 1998. Winter wheat is normally rotated with fallow, but was replaced with spring wheat in 1998.

In April 1999 at Palouse, water in the soil profile was 20 inches under DS compared to 17 inches under conventional management. These results suggest that the residue cover under DS probably allowed for better water infiltration and less evaporation than conventional management over the winter months.

Table 1. Agroclimate zones, locations, and production systems in 1997

Rainfall zone	Location	Production system/comparison
High	Palouse, WA	20+ y DS wheat-barley-pea vs. first year DS
	Pullman, WA	16 y DS continuous wheat vs conventional
	Colfax, WA	10 y DS mostly wheat, some lentil vs. conventional
Intermediate	Lewiston, ID	DS winter wheat (1980-92), 3 y rotation since vs. conventional
	St. John, WA	15 y DS wheat-fallow vs. conventional
Low	Touchet, WA	14 y continuous DS spring wheat vs. wheat-fallow

Table 2. Ponded infiltration rate (cm/hr)

Location	Conventional	Direct Seed
St. John	1.1	2.4
Lewiston	10.5	18.0
Colfax	2.4	3.6
Palouse	5.9	6.9

Table 3. Fall 1997-1998 total precipitation, total water consumed, crop yield, and crop water use efficiency (WUE) under conventional and DS systems.

Location	Crop	System	Precipitation (in.)	Water used (in. to 5 ft)	Yield (Bu/ac)	WUE (Bu/in. water)
Palouse	Winter wheat	conv.	13.49	20.63	96.8	4.7
	Winter wheat	DS	13.49	19.84	131.2	6.1
Touchet	Spring wheat	conv.	1.93	8.22	40.5	4.9
	Spring barley	DS	1.93	7.99	51.8	6.5

ACKNOWLEDGEMENTS
We appreciate the cooperation of the following growers: Mike Cronk, Duane Kjack, Frank Lange, Dick Lloyd, Roger Pennell, Bob Rea, John Rea, Rick Repp, and Garry Schwank in providing plot land.

Performance of Advanced Lines and Varieties of Spring Barley Seeded Directly into Wheat or Barley Stubble

R. James Cook, Steve Ullrich, William Schillinger, and Steve Dofing

In addition to erosion control, direct-seeding offers the means to increase the diversity and intensity of cropping in the low- and intermediate-precipitation areas traditionally dependent on a winter wheat/summer fallow rotation, thereby broadening the economic base of the farm and spreading risks over more crops. Areas that currently produce five crops in each field every 10 years have the potential with direct seeding to produce seven or eight crops while cutting the years of summer fallow in half or even less. Areas that currently use a winter wheat/spring cereal/summer fallow rotation have, with direct seeding, the potential to eliminate summer fallow all together.

Direct-seed cropping systems fall into two general groups—those that include at least one broad leaf crop every 3rd or 4th year and those that depend entirely on cereals with no broad leaf crop in the rotation. Since winter wheat should be the crop of choice after a broad leaf crop, regardless of the cropping system, any spring barley used in the rotation invariably will be planted into the stubble of a cereal, either winter or spring wheat or spring barley. Fortunately, spring barley has proven particularly well-suited to direct seeding into cereal stubble. Rhizoctonia root rot has been the most apparent hazard faced with direct-seeded barley, but tools such as greenbridge management and fertilizer placement are helping greatly to reduce the risk of this disease. Research and grower experience has shown that virtually any drill equipped to 1) place seed through surface residues into good soil contact, 2) place fertilizer directly below or below and slightly to one side of the seed, 3) loosen soil beneath the seed for seminal root penetration, and 4) ideally also clear trash from within the seed row will be acceptable.

Further significant advancements towards achieving the high yields possible with direct-seeded spring barley will come with development of varieties with resistance or tolerance to the hazards encountered with this method of farming. Towards this end, research is underway on two fronts: Evaluation of existing varieties to determine their suitability to direct seeding, and identification or development of barley germplasm with resistance to Rhizoctonia root rot for use in the breeding program. In addition to greenhouses tests, a field test to screen both spring barley and spring wheat for resistance to Rhizoctonia root rot was initiated on Spillman Farm in 1998. The development of Rhizoctonia resistant varieties is a long-term effort, although some progress has been made in identification of lines with either resistance or tolerance to this disease.

Of more immediate interest is the work underway on performance of spring barley varieties direct seeded into cereal stubble in the low- and intermediate-precipitation areas.
The variety evaluation studies were begun about five years ago on a site near Dusty. The tests were expanded three years ago to include a site near Ritzville, and in 1998, tests were conducted at three sites, namely Dusty, Ritzville, and Bickleton. For 1999, we have expanded the program again to include a second site at Ritzville. All tests are done with excellent greenbridge management and a one-pass system that seeds and places fertilizer and loosens the soil directly beneath the seed. Except for the 1997 test at Ritzville, which was seeded into spring barley

stubble, all tests have been with spring barley seeded directly into stubble of winter wheat. Yields of a select subset of varieties tested to date are presented in Table 1.

In general, the yields have been good to excellent. Yields at the Dusty site were disappointingly low in 1998, including in fumigated plots, indicating that the problem was not caused by root diseases. As with experience with conventional seeding Baronesse has been at or near the highest yielding spring barley in these tests.

Table 1. Yields of spring barley seeded directly into stubble of winter wheat (Dusty, 1995 and 1997) or spring barley (Ritzville, 1997).

	Dusty	Ritzville		Dusty		Bickleton
	1995	1997	1998	1997	1998	1998
Variety	(lbs/A)	(lbs/A)	(lbs/A)	(lbs/A)	(lbs/A)	(lbs/A)
Steptoe	4316	3159		4125		
Crest	4006	2524	2644	3788	3079	1961
Harrington	3895		2549	3799	2549	1806
Colter	5023	2718		4260		
Baronesse	4158	2955	2899	4373	3120	2022
Meltan	5023	2855	2571	3639	2993	1550
Camelot	4503		2635	4430	3147	1583
Gallatin	3900		2679	3816	2679	1748
Maranna	4841			4023		
WA 9792-90	5263			4218		
Chinook			2635		2622	1559
WA 7114-93			2475		2788	1603
WA 8772-93			2514		3093	1650
WA 8394-93			2509		2534	1596

Performance of Advanced Lines and Varieties of Spring and Winter Wheats Seeded Directly into Cereal Stubble

R. James Cook, Steve Jones, Kim Kidwell, and Steve Dofing

Efforts have been underway for the past 3 years to evaluate the performance of a limited number of advanced lines and standard varieties under direct-seed conditions in the field. The project was begun in 1995/1996 crop year with a spring-wheat test on winter wheat stubble near Dusty and a winter-wheat on spring wheat stubble near Pullman. The project was expanded in the 1996/1997 crop year to include two spring-wheat tests near Colfax and Pullman, respectively, and one winter-wheat test near Colfax. The project was expanded further in the 1997/1998 crop year to include two spring-wheat tests near Colfax and Bickleton, respectively, and three winter-wheat tests near Colfax, Bickleton, and Pullman.

All trials have been conducted with wheat seeded directly into wheat stubble -- the highest-risk system for direct seeding. Typically, winter wheat has been seeded into spring wheat stubble and spring wheat has been seeded into winter wheat stubble. All tests have been done without burning the stubble. Furthermore, all fertilizer has been placed within the seed rows and directly below the seed, with N rates based on soil tests. Except for the 1996 site at Dusty, all sites have been in no-till for at least 3 years. The Pullman site has been in no-till for 15, 16, and 17 consecutive years for 1996, 97, and 98, respectively. The Pullman site is rotated between spring and winter wheat, hence we only have data every other year for any given kind of wheat at this location. Soil fumigation and seed treatments have been included at some sites to evaluate the importance of root diseases in these systems.

In general, the yield of spring wheat lines and varieties are well within the range expected with conventional tillage and planting (Table 1). The high yields in 1997 at Pullman are exceptional, considering that 1997 was the 16th consecutive year of no-till and 12th wheat crop in 15 years for this site. Hessian fly damage occurred at the Bickleton site in 1998, which accounts for the low yields of fly-susceptible and high yields for fly-resistant varieties at this site. Winter wheat yields (Table 2) likewise are well within the range expected for these lines and varieties, especially when considering that the yields obtained all are without benefit of summer fallow. The yields at the Pullman site are also encouraging, considering that the site was in the 15th year of continuous no-till in 1996 and 17th year of continuous no-till in 1998.

Root diseases, including Rhizoctonia root rot, Pythium root rot, and take-all, are among the major constraints to yields of both winter and spring wheats planted directly into cereal stubble without benefit of fallow or a broadleaf crop in the rotation. Table 3 gives yields in response to soil fumigation and seed treatments tested at the same location during 1998. In 1997, the yield of Madsen at Colfax was 72 bu/A without fumigation and 106 bu/A with fumigation. In 1998, yields at the Colfax site were not increased by soil fumigation for winter wheat (Madsen), but were increased by 16 bu/A (35%) for spring wheat (Alpowa). At Bickleton, the yield of Madsen was increased by 19 bu/A in 1998 in response to fumigation. The yields in fumigated plots shows the potential for winter and spring wheats planted directly into cereal stubble.

Seed treatments provide modest protection of the germinating seed and emerging seedling against early infections by root pathogens, but little or no protection. It is for this reason that yields commonly are not increased by seed treatments.

Table 1. Average yields of spring wheat lines and varieties seeded directly (no-till) into standing stubble of winter wheat.

Variety	1996 Dusty (bu/A)	1997 Pullman (bu/A)	1998 Bickleton (bu/A)	1998 Colfax (bu/A)
Penawawa	40.0	71.5	18.3	45.8
Edwall		72.3	20.7	46.3
Pomerelle	42.4	56.8	14.8	37.4
Centennial	41.9	63.7		48.1
Vanna	38.4	66.7	18.4	37.9
Alpowa	39.5	66.3	20.7	47.2
Wawawai	38.7	68.8	32.1	46.9
Whitebird	44.1	66.7	15.5	47.1
ID3775		71.3	16.9	50.1
WPB926		54.4		
Express		71.0	18.7	47.2
WA7802		64.2	20.8	52.2
WA7824			29.8	55.4
WA7850			32.9	52.4
WPB926R			29.4	50.0
Westbred 936			17.0	46.1
Butte 86			21.6	45.9
Wadual				40.4
Kulm				43.0
Germains #10				47.4
Location Average	40.7	66.1	21.8	46.7

Each value is an average of six replicates of 8-row plots 24-feet long.

Table 2. Average yields of winter wheat lines and varieties seeded directly into standing stubble of spring wheat.

Variety	1996 Pullman (bu/A)	1997 Colfax (bu/A)	1998 Bickleton (bu/A)	1998 Colfax (bu/A)	1998 Pullman (bu/A)
Madsen	89.0	72.5	38.3	78.6	82.2
Stephens			38.2	77.4	85.7
Eltan	104.7	92.7	39.2	71.4	67.0
Moro	68.5		31.6		
Hiller	101.9	85.3	38.6		75.7
VH091505	111.0	82.4			
VH091239	105.8	72.5			
WA7835		86.3	41.2	78.1	86.2
WA7833		80.3	40.1	77.9	76.8
Rely			38.0	71.9	70.2
Rod			38.3	75.4	76.7
WA7834		73.6	33.1	59.0	62.7
WA7752			41.0	76.5	76.3
Rohde			37.2	74.3	69.5
OR92054			37.7	73.6	76.6
Lewjain			36.0		66.1
Location Average	96.8	80.7	37.8	74.0	74.8

Each value is an average of six replicates of 8-row plots 24-feet long.

Table 3. Yields of winter and spring wheats at the indicated locations for 1998 in response to soil fumigation with methyl bromide or seed treatment with either Raxil-Thiram or Dividend-Apron.

Treatment	Bickleton	Colfax (bu/A)	Pullman
Madsen			
Check	39 b	79	82
Fumigated	58 a	80	
Raxil-Thiram	39 b	75	74
Dividend-Apron	39 b	72	82
		NS	NS
Alpowa			
Check		46 c	
Fumigated		62 a	
Raxil-Thiram		55 b	
Dividend-Apron		45 c	

Yield Trends in a Long-Term Continuous Direct-Seed Winter Wheat/Spring Cereal Cropping System

R. James Cook, Ron Sloot, and Kurt Schroeder

Direct seeding works best in the Inland Northwest when combined with a 3- or 4-year crop rotation that includes cereal crops alternated with broadleaf crops or chemical fallow -- with winter wheat no more than every third year. However, the Inland Northwest is among the least suited of all wheat- and barley-growing areas in the United States for production of warm-season crops, which greatly limits the number of broadleaf crops available for rotation with wheat and barley. The good news is that the Inland Northwest is one of the few areas in the world that is more or less equally suited to production of both winter and spring wheat and barley. These ecological realities and the limited number of economically viable cool-season broadleaf crops available for use in crop rotations within this region can account for why growers continue to plant two-thirds or more of their land to wheat and barley each year.

A study was undertaken the fall of 1987 on the Palouse Conservation Field Station near Pullman to evaluate yield trends and study root diseases with continuous direct seeding. The site had already been direct-seeded to winter wheat for five consecutive years (1981-1986) and was then chemical fallowed in 1986-87 prior to launching this study. The current (1999) planting therefore represents the 18th consecutive year where the only tillage performed on this site has been with the drill equipped to plant and fertilize as one-pass. During the 12 years (including 1999) that crops have been grown with direct seeding since the year of chem fallow, the site has been planted to winter wheat four times, spring wheat six times, spring barley once (1993) and spring peas once (1994), making a total of 15 wheat crops and 16 cereal crops in the past 18 years. Rotations to spring cereals have been essential to manage cheat grass and jointed goat grass. Fumigation plots were included as checks during 1987-92 but were then discontinued. Many replicated seed-treatment, variety, row-spacing, and fertilizer-placement studies have been conducted at the site. The study site has never been burned during the 18 years, but has been planted each year across the direction of the rows of the previous year so as to place maximum amount of seed between rather than within the old stubble rows.

The data in Table 1 present yields in the untreated (natural soil) and fumigated checks together with six years for data on performance of Apron with either Terrachlor or Dividend for management of Pythium and Rhizoctonia, respectively. For each of these yields, rows have been spaced 12 inches apart and fertilizer has been applied directly beneath the seed as a combination of N (solution 32), P, and S based on a soil test (by McGregor Co) and yield goal (usually 100-110 bu/A for winter wheat and 70-80 bu/A for spring wheat).

The highest yield of winter wheat (Daws, at 128 bu/A in 1988) and spring wheat (Penawawa, at 99 bu/A in 1995) were following the years of chemical fallow and peas, respectively. This confirms the value of a break to either fallow or a broadleaf crop before planting wheat, whether winter wheat or spring wheat. There was no response of the Daws to soil fumigation after the 1-year break to chemical fallow nor of the Penawawa to Apron-Terrachlor after the 1-year break to peas, confirming the importance of crop rotation for control of root diseases.

The lowest yields of winter and spring wheat were in the second (Hill-81 at 57 bu/A in 1989) and third (Penawawa at 49 bu/A in 1990) years respectively. In both of these years, there was a large yield response to Apron-Terrachlor, soil fumigation, or both, further confirming the role of root diseases in these yield depressions. The low yield of Penawawa in 1992 was possibly the result of high temperature during grain fill. The first evidence of take-all decline (the spontaneous disappearance of take-all due to microbiological changes in the wheat rhizosphere) appeared in 1996 and was confirmed by Jos Raaijmakers and Dave Weller in 1997 using their lab test. Starting in the 1995-96 crop year, the site has been used to evaluate the performance of varieties and selections of winter wheat (cooperative with Steve Jones) and spring wheat (cooperative with Kim Kidwell).

Table 1. Long term yield trends in a continuous direct-seed winter wheat-spring cereal cropping system at Pullman, WA (Palouse Conservation Field Station)

	Year	Variety	Check bu/A	w/Apron +PCNB or Apron +Dividend bu/A	Fumigated bu/A
1-5	1981-86	Continuous direct-seeded winter wheat; yield data not available			
6	1986-87	Chemical Fallow			
7	1987-88	Daws	128		124
8	1988-89	Hill-81	57	57	72
9	1989-90	Penawawa	49	57	76
10	1990-91	Penawawa	65		86
11	1991-92	Penawawa	55		7
12	1992-93	Steptoe Barley	(~3.0t/a)		
13	1993-94	Peas			
14	1994-95	Penawawa	99	101	Discontinued
15	1995-96	Madsen	87	101	
16	1996-97	Alpowa	69	75	
17	1997-98	Madsen	82	82	
18	1998-99	Alpowa			

These results suggest that yields of continuous direct seeded wheat can be maintained or expected to increase over the long term, provided that spring cereals are used to manage cheat grass and jointed goat grass. Rotation to broadleaf crops not only break up pest cycles, but unfortunately, this also disrupts the microbiological process responsible for take-all decline, although the evidence suggests that reestablishment of a take-all suppressive soil is relatively fast during a second and subsequent years of wheat monoculture. Growers might consider dedicating one portion of their land to a continuous direct-seeded winter wheat/spring cereal cropping system and the other portion, e.g. the most productive land, to a 3- or 4-year direct-seeded, crop rotation.

Long-Term Alternative Cropping Systems Research for the Drylands

Researchers: William Schillinger, R. James Cook, Keith Saxton, Robert Papendick, Harry Schafer, Doug Young, Robert Gillespie, Ann Kennedy, Joe Yenish, Tom Lumpkin, Roger Veseth, John Driessen, and Bruce Sauer. Washington State University and USDA-Agricultural Research Service.

Grower Cooperators: Ron Jirava, Ritzville; Brad Wetli, Mansfield

OBJECTIVES: To determine the long-term feasibility of diverse, no-till annual cropping systems for low-rainfall dryland areas of the inland Pacific Northwest. Specific objectives are:

1. Develop long-term rotations which include alternative crops such as yellow mustard and safflower, and measure their effects on root diseases and grain yield of subsequent wheat and barley crops.
2. Document the long-term cumulative effects of minimum disturbance no-till planting practices on physical and biological properties of the surface soil.
3. Demonstrate and promote no-till farming practices and alternative crop rotations to growers and agricultural support personnel.
4. Assess the feasibility of alternative crops for low-rainfall dryland production areas.

The Problem: For most of a century the wide-spread practice of growing only one crop every other year in a tillage-based wheat-fallow rotation has degraded soils and contributed to environmental problems in low-rainfall (less than 12" annual) dryland areas of the inland Pacific Northwest. Soil organic carbon, and associated soil quality, are declining under the wheat-fallow system because of limited crop residue production, tillage, and the unproductive fallow period. Blowing dust from excessively tilled summer fallow is a major soil loss and air quality concern. In addition, water erosion from fall-planted wheat after fallow is often severe when rain or snowmelt occur on frozen soils. Growers in dryland areas are interested in no-till planting techniques and potential alternative crop rotations which reduce erosion, decrease soil-born diseases of cereals, enhance crop marketing opportunities, and hold potential to increase soil quality.

Rainfall Zone: The low-rainfall (6-to 12-inch annual) dryland area of east-central Washington and north-central Oregon. This zone encompasses 3.5 million cropland acres.

Interpretive Summary: We have completed two years of a long-term study to evaluate alternative cropping systems for low-rainfall dryland areas using minimum disturbance no-till. The experiment sites are near Ritzville (Ron Jirava farm) and Mansfield (Brad Wetli farm). We are comparing a 4-year rotation which includes two years of spring wheat followed by two years of broad leaf crops, continuous wheat, and continuous wheat - barley. Research highlights for 1998 are: Rhizoctonia root rot in cereals was lowest at Ritzville when the preceding crop was yellow mustard rather than cereals; wheat yields at both sites were highest when the preceding crop was yellow mustard; weed populations increase with broadleaf crops but can be effectively controlled when the rotation reverts back to cereals; aphid populations were much lower than in 1997 and; yellow mustard and safflower yields were reduced due to hot temperatures in late June and July.

A new Cross-slot drill and a new plot sprayer will be available to this project in 1999 which will allow us increased flexibility and efficiency in planting and weed control.

METHODS

This project, which began in April 1997, is evaluating diverse, annual, no-till cropping systems as a substitute for winter wheat - summer fallow. Research sites are located at the Ron Jirava near Ritzville in Adams county, and at the Brad Wetli farm NW of Mansfield in Douglas county. At both sites, the following rotations are studied:

	Year 1	Year 2	Year 3	Year 4
Four-year rotation (main)	wheat	wheat	safflower	yellow mustard
Wheat-barley rotation	wheat	barley	wheat	barley
Continuous spring wheat	wheat	wheat	wheat	wheat

The experimental design is a randomized block with four replications, and each portion of the rotation is planted each year (i.e., 28 plots are required at each site). The Ritzville site receives an average of 11.5 inches annual rainfall, soils are more than six feet deep, and elevation is 1850 ft asl. At Mansfield, rainfall averages 10.5 inches, soil is only 2-to-2.5 ft deep, and elevation is 2700 ft asl. The no-till drills used in the study are a grower-owned Flexi-coil 6000 disc drill with 7.5" row spacing at Ritzville, and a Cross-slot disc drill with 10" row spacing at Mansfield. Both drills deliver seed and all fertilizer in a single pass through the field.

RESULTS

Plant Stand Establishment: Plots are fertilized at time of planting with nitrogen, phosphorous, and sulfur as indicated by soil tests in early spring. Seed rates in 1997 and 1998 were wheat 70-to-90 lb/a, barley 65-to-70 lb/a, safflower 20 lb/a, and yellow mustard 7-to-10 lb/a. Plant stands for all crops at both sites in 1997 and 1998 are shown in Table 1. Despite large seed size, stands of safflower have been relatively thin at both locations during both years. Yellow mustard stands were thin at both locations in 1998 which makes us wonder if safflower residue might have a phytotoxic effect on mustard seedlings. Acceptable stands of wheat and barley have been achieved at both locations each year.

Weeds: Russian thistle, horse tail, and prickly lettuce were problem weeds in yellow mustard and safflower crops in 1997 and 1998. There are no registered "in-crop" herbicides broadleaf weed in yellow mustard or safflower, therefore control measures are limited to pre-plant herbicide application and competition. Broadleaf weed dry biomass in 1998 at time of harvest for yellow mustard and safflower averaged 700 lb/a at Ritzville and 1900 lb/a at Mansfield (data not shown. At Ritzville we are able to stagger planting of crops whereas in Mansfield, due to demands for the Cross-slot drill in other areas, we plant all crops on the same day. When safflower is planted early it emerges at the same time as Russian thistle (Mansfield), whereas Russian thistle is much less a problem when safflower planting is delayed (Ritzville). We will have a new Cross-slot drill available in 2000 which will allow us to optimize planting dates for crops at Mansfield.

Table 1. Plant stand establishment of four crops sown no-till at Ritzville and Mansfield in 1997 and 1998. Plots at Ritzville were sown with a Flexi-coil 6000 disc drill and at Mansfield with a Cross-slot disc drill.

Crop	Location and Year†			
	Plants per ft^2			
	Ritzville		Mansfield	
	1997	1998	1997	1998
Safflower after y. mustard	2.5	3.2	5.0	3.8
Y. mustard after safflower	1.8	0.7	7.0	2.4
Barley after wheat	8.6	15.3	10.3	20.4
Wheat after barley	---	20.7	---	22.2
Wheat after y. mustard	---	20.0	---	20.5
Wheat after wheat	9.6	18.6	10.9	26.2

† All crops were planted into spring wheat stubble in 1997, which was the first year of the study.

Good weed control in barley and wheat was achieved at Ritzville in 1997 and 1998 with 6 oz. Salvo plus 0.3 oz. Harmony Extra applied during the tillering stage. There were no differences in 1998 in weed populations in wheat when the previous crop was either yellow mustard or wheat (data not shown), which demonstrates that an elevated weed population in broadleaf crops can be brought back under control when the crop rotation returns to cereals. Weeds in barley and wheat were controlled with 2,4-D in 1997 at Mansfield, but we missed the opportunity to spray for broadleaf weeds in cereals in 1998, and wheat after yellow mustard had significantly more weeds than wheat after wheat.

Root Rot Assessment: Rhizoctonia root rot is the most important disease of spring cereals planted directly into cereal stubble in the Pacific Northwest. Wheat and barley plants were dug from plots in 1998 at both sites to measure the severity of root rot disease. At least 5 plants were dug from each of 5 separate locations in every plot to make a composite sample. Jim Cook and his assistants determined Rhizoctonia root rot severity of both seminal roots and crown roots, along with other measurements.

The percentage of Rhizoctonia infection at Ritzville on both seminal roots and crown roots of cereals was lowest when yellow mustard was the preceding crop (Table 2). We are very encouraged with these data because Rhizoctonia can be devastating to cereals under no-till, and we believe broadleaf rotation crops are necessary to control this disease in continuous ultra low-disturbance no-till systems. No differences in Rhizoctonia infection were found at the Mansfield site in 1998.

Yield: Yields for all four crops grown at Ritzville were reduced in 1998 compared to the bumper harvest in 1997 (Table 3). Stored over-winter soil water and growing season rainfall were greater in 1997 than in 1998 (data not shown). In addition, hot air temperatures exceeding 90^{0}F in late June and July 1998 stressed and reduced yields of yellow mustard and safflower. Where yellow mustard was the preceding crop, wheat yield was 1.6 bu/a higher compared with wheat following wheat (Table 3).

Broadleaf yields were low at Mansfield which reflects a combination of very shallow soils, less than optimum planting date for the safflower, high weed density, and hot summer temperatures. Spring barley averaged 1.0 ton/a. Wheat yield exceeded 25 bu/a and was best on plots where yellow mustard was the previous crop (Table 3).

Table 2. Incidence of Rhizoctonia root rot on seminal and crown roots of spring wheat and spring barley 1998 at Ritzville and Mansfield in response to rotation. Crops are planted annually using no-till in a 4-year rotation at both sites.

Rotation Crop 1997	1998	Rhizoctonia Infection (%) Seminal Roots	Crown Roots
Ritzville			
Wheat	Wheat	18.5 ± 2.3	5.3 ± 1.0
Yellow Mustard	Wheat	10.8 ± 1.5	2.2 ± 0.4
Wheat	Barley	16.9 ± 2.2	5.2 ± 0.7
Barley	Wheat	17.2 ± 1.9	5.3 ± 0.6
Mansfield			
Wheat	Wheat	15.1 ± 1.6	11.5 ± 1.1
Yellow Mustard	Wheat	18.6 ± 2.1	16.2 ± 1.2
Wheat	Barley	27.1 ± 2.2	23.6 ± 1.8
Barley	Wheat	17.6 ± 2.1	13.0 ± 1.1

Source: R.J. Cook

Table 3. Yields of four crops planted no-till at Ritzville and Mansfield in 1997 and 1998. These are second year results of a planned six-year alternative cropping systems project.

Crop	Units	Location and Year†			
		Ritzville		Mansfield	
		1997	1998	1997	1998
Safflower after y. mustard	lb/acre	1420	720	630	340
Y. mustard after safflower	lb/acre	1430	340	410	140
Barley after wheat	t/acre	2.30	1.13	1.20	1.00
Wheat after barley	bu/acre	---	40.6‡	---	25.5
Wheat after y. mustard	bu/acre	---	41.1	---	27.6
Wheat after wheat	bu/acre	64.3	40.5	19.2	26.2

† All crops were planted into spring wheat stubble in 1997, which was the first year of the study.

‡ Wheat yields in 1998 at either the Ritzville or Mansfield site were not significantly different at the 5% probability level.

Other Measurements: Insect populations/ecology in all crops were measured several times throughout the growing season at both sites in 1997 and 1998 (Bob Gillespie) and we plan to write a scientific journal and popular article from these data in the next year. Herbicide screening experiments for broadleaf weed control in yellow mustard and safflower were conducted at the Ritzville site (Joe Yenish). Baseline soil samples have been collected at both sites (Ann Kennedy). Root disease assessment will continue (Jim Cook).

COMPANION STUDY: A long-term no-till project was initiated at the WSU Dryland Research Station at Lind in 1998. We are using the Cross-slot drill to annually plant wheat, barley, oats, and safflower as spring crops and to compare winter wheat (when fall rainfall allows) to spring wheat on an annual basis.

For more information on this project, contact William Schillinger at (509) 659-0355 or e-mail schillw@wsu.edu.

Water Use by Alternative Crops

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Many growers in the dryland region want to intensify cropping and reduce fallow. Alternative crops are needed in cereal-based cropping systems to reduce soil born diseases such as Rhizoctonia root rot, which can severely reduce yields when cereals are planted back-to-back for several years. Water is the most limiting factor in the dryland area. An understanding of the timing and extent of water extraction and its relation to dry matter accumulation of alternative crops need to be evaluated.

Methods: Alternative crop nurseries were sown in the spring at several locations throughout the inland Pacific Northwest by Western Farm Service personnel in 1998. We measured water use and dry matter accumulation of eleven crops at the WSU Dryland Research Station at Lind, the Don and Doug Wellsandt farm near Ritzville, and the Karl Kupers farm near Harrington. Crops were peas, lentils, barley, soft white wheat, canola, yellow mustard, linola, corn, millet, sunflower, and safflower. Soil moisture readings were obtained by neutron attenuation to a depth of six feet on several occasions. Biomass samples were periodically obtained, dried, and weighed throughout the spring and summer.

Results: Crops can be roughly divided into the following categories: 1) warm season grasses - millet, corn; 2) warm season oilseeds - safflower, sunflower; 3) cool season oilseeds - linola, canola, yellow mustard; 4) cool season grasses - wheat, barley; 5) cool season legumes - lentils, peas. Crop year precipitation in 1998 was normal at Lind and Harrington and above normal at Ritzville (Table 1). All three sites received 1.50 inches of rain or more in a two day period in mid May. Warm season crops at the Ritzville site further benefited from a downpour of more than one inch on July 10.

Total soil water use and dry matter production of individual crops at each of the three locations are shown in Fig. 1. The cool season legumes (lentils and peas) extracted water only in the first few feet of soil and used significantly less total water than the other crops at all sites. Water use by spring wheat, spring barley, yellow mustard, and canola were similar. Safflower removed the most water from the soil at all locations. The quantity of water and the depths from which water is extracted is important for determining water availability for subsequent crops.

This research project is continuing in 1999. The authors thank WSU Technical Assistant Steve Schofstoll of Ritzville, WA, for help in the field and in data analysis.

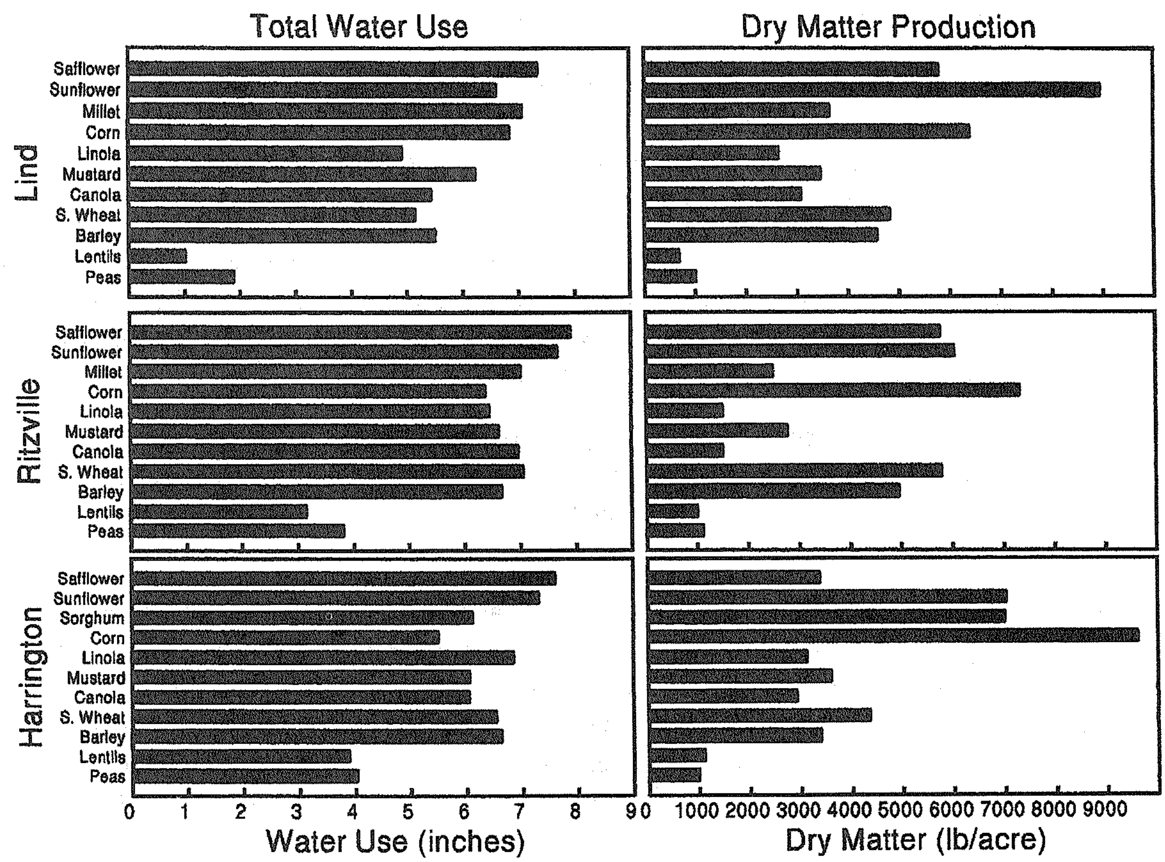

Fig. 1. Total water use and dry matter production of eleven crops grown at three locations in 1998

Table 1. Precipitation at three research sites during the 1998 crop year.

	Location		
	Lind	**Ritzville**	**Harrington**
Sept. thru April	7.10	10.07	9.19
May	1.50	2.14	2.06
June	0.09	0.46	0.21
July	0.48	1.39	0.45
August	0.30	0.45	0.13
12 month total	9.47	14.51	12.04

Spring Grain Annual Cropped Response Trial Results for 1998

K. Kidwell, S. Ullrich, G. Shelton, V. Jitkov, and F. Young

Objective: Evaluate the field performance of spring wheat and spring barley varieties under conventional tillage and direct seed production systems in an annual cropping situation.

Plant Material: Twelve spring wheat and 12 spring barley varieties were selected for evaluation based on preliminary fiber analysis data provided by Dr. A. Kennedy (USDA-ARS). Due to performance differences across agronomic zones, spring wheat entries differed for the two field trials. Spring barley entries were identical across locations.

Field Evaluation: The trial was designed as a split plot with tillage treatment as the whole plot factor and variety as the sub-plot factor with 4 replications at two locations: Dusty (16" avg. annual rainfall) and Ralston (11" avg. annual rainfall).

A. **Ralston**: This was the third year that this trial was planted at the Ralston site; however, the 1996 establishment year data will not be included in final analyses. Each year, the same variety is sown in the same plot. On November 17, 1997, 34 lb of ammonium nitrate (granular fertilizer formula: 34-0-0) was applied to the field. The following spring, an additional 76 and 90 lb of N were applied to the conventional and direct seeded plots, respectively. The field was sprayed with Round-up prior to planting. The direct seed treatment was planted into standing stubble, whereas the conventional plots were rotary hoed prior to seeding. The trial was planted on March 25 with a six row Wintersteiger plot planter using hoe openers with 8 inch row spacings, placing 4 lb N and 14 lb P_2O_5 with the seed. Plot size was 10 ft x 30 ft. Seeding rates of 75 lb/A for spring wheat and 24 seed/ft^2 for spring barley were used for conventionally tilled plots, whereas direct seeded plots were sown at a rate of 85 lb/A for spring wheat and 27 seed/ft^2 for spring barley. These seeding rates reflect a 15 lb/A increase compared 1997 rates, and seeding rates of direct seeded plots were increased by an additional 10 lb/A. Post-establishment herbicide application for weed control was not required at this site.

B. **Dusty**: This was the second year that the annual crop response trial was grown at Dusty; however, tillage treatments were not established at this location until 1998. The 1997 data will be used as a base line for comparing the impact of tillage treatments on agronomic performance of varieties over time. Due to high nitrogen residual, the fertility management strategy used at Dusty was identical to the one described for Ralston in 1998. The trial was planted as described above except that the planting date was March 30, 1998. On May 19th, the field was sprayed with a Buctril, Harmony Extra, Hoelon mixture to control weeds.

Data Collection: Heading dates, plant heights, grain yields, test weights and grain protein contents, as determined by the NIR whole kernel analyzer, were recorded.

1998 Data Summary for Spring Wheat

1. **Ralston:**
   a. Grain yield averages did not differ significantly across tillage treatment (Table 1). The seeding rate and fertility adjustments may have contributed to the success of these varieties in direct seed production.

b. Tillage did have an impact on the agronomic performance of some entries in this trial (Table 2). In most cases, varieties produced more grain with conventional tillage; however, ID488, a Russian wheat aphid resistant line, produced 4 bu/A more grain when direct seeded compared to conventional production.
c. Grain protein content (GPC) of direct seeded varieties were significantly higher than GPCs of conventionally tilled entries. All no-till hard red entries, except for Wampum, achieve the protein premium specification, whereas only one entry made protein in the conventionally tilled plots.
d. Since yield differences across tillage treatment and between market classes were negligible, and most of the hard red varieties had GPCs of 14% or higher when direct seeded, annual cropped, direct seed production of hard red spring wheat was the system of choice at Ralston in 1998.

2. Dusty:

a. No significant differences between the agronomic performance of entries grown in conventional and direct seed production systems were detected at Dusty in 1998 (Table 1).
b. Grain yield averages of hard red entries exceeded those of soft white entries in both tillage treatments at this locations by approximately 2.5 bu/A (Table 2).
c. All hard red entries in both tillage systems made protein at Dusty (Table 3). GPC of hard read varieties were slightly higher when direct seeded compared to conventional production.
d. Annual cropping hard red spring wheat using tillage system appears to be an economically viable alternative to annual soft white spring wheat production at Dusty.

3. 1998 Spring Wheat Data Combined Over Locations

a. Significant location effects were detected for all traits, and the highest yielding entries differed by location. Alpowa, WA7864 and Scarlet were among the highest yielding entries in both tillage treatments at Ralston, whereas Express and WA7824 were the highest yielding entries in both tillage systems at Dusty.
b. Impact of tillage treatment on agronomic performance differed by location. GPC and plant height were highly influenced by tillage treatment at Ralston, whereas tillage treatment had little impact on the agronomic performance of varieties grown at Dusty.
c. GPC were higher for entries grown at Dusty than entries grown at Ralston even though test weight averages at Dusty were over 2 lb/bu higher than those for entries grown at Ralston. This was probably associated with the high nitrogen residual levels in the soil at the Dusty.

Table 1: Trait means for spring wheat varieties grown under conventional tillage or direct seeded at Ralston and Dusty, WA in 1998.

	Ralston.		Dusty	
Trait	Conventional	Direct	Conventional	Direct
Yield (bu/A)	37.7	36.4	70.7	70.1
Test weight (lb/bu)	56.4	56.5	58.8	58.8
% Protein	13.1	13.8*	13.4	13.5
Plant Height	25.0*	23.7	32.3	31.8

*Trait mean was significantly higher (P = 0.10) between tillage treatments within each location based on paired t-test comparisons.

Table 2: Grain yields and protein contents (with rankings in parenthesis) for spring wheat varieties grown under conventional tillage or direct seeded at Ralston WA in 1998.

		Grain Yield (bu/A)		% Protein	
Variety	Class[1]	Conventional	Direct	Conventional	Direct
WPB936	HRS	38 (6)	35 (9)	13.6 (3)	15.2 (1)
WA7798	HRS	34 (11)	34 (11)	14.6 (1)	14.6 (2)
Express	HRS	40 (3)	36 (7)	13.4 (5)	14.5 (3)
Scarlet	HRS	39 (5)	38 (2)	13.3 (8)	14.3 (4)
Butte 86	HRS	36 (9)	33 (12)	13.6 (3)	14.3 (4)
WA7764	HRS	41 (1)	39 (1)	13.4 (5)	14.2 (6)
Spillman	HRS	36 (9)	35 (9)	13.7 (2)	14.0 (7)
Idaho 377s	HWS	37 (8)	38 (2)	13.4 (5)	14.0 (7)
Wampum	HRS	38 (6)	37 (6)	12.9 (9)	13.6 (9)
ID488	SWS	34 (11)	38 (2)	11.9 (11)	12.3 (10)
Wawawai	SWS	40 (3)	36 (7)	12.2 (10)	12.8 (11)
Alpowa	SWS	41 (1)	38 (2)	11.3 (12)	11.7 (12)

[1]SWS = soft white spring; HRS = hard red spring; HWS = hard white spring
LSDs (10%) were 3 bu/A for yield and 0.4% for protein for both tillage treatments.

Table 3: Grain yields and protein contents (with rankings in parenthesis) for spring wheat varieties grown under conventional tillage or directed seeded at Dusty WA in 1998.

		Grain Yield (bu/A)		% Protein	
Variety	Class[1]	Conventional	Direct	Conventional	Direct
Butte 86	HRS	73 (3)	70 (6)	14.7 (1)	15.2 (1)
WPB936	HRS	69 (8)	68 (8)	14.4 (2)	14.4 (2
WA7824	HRS	77 (2)	75 (2)	14.3 (3)	14.3 (3)
WPB926	HRS	70 (7)	72 (3)	14.2 (4)	14.3 (3)
Spillman	HRS	62 (12)	64 (12)	14.1 (7)	14.3 (3)
Scarlet	HRS	71 (6)	70 (6)	14.2 (4)	14.1 (6)
Express	HRS	83 (1)	79 (1)	14.2 (4)	14.0 (7)
Idaho 377s	HWS	67 (9)	72 (3)	13.3 (8)	13.6 (8)
Wawawai	SWS	67 (9)	68 (8)	12.4 (9)	12.8 (9)
Penawawa	SWS	65 (11)	65 (11)	11.9 (11)	12.0 (10)
ID488	SWS	73 (3)	71 (5)	11.9 (11)	11.8 (11)
Alpowa	SWS	72 (5)	68 (8)	11.3 (10)	11.2 (12)

[1]SWS = soft white spring; HRS = hard red spring; HWS = hard white spring
LSDs (10%) were 10 bu/A and 4 bu/A for yield and 0.5% and 0.4% for protein for conventional tillage and direct seed production, respectively.

1998 Data Summary for Spring Barley

1. Ralston:

a. Grain yield averages differed significantly between tillage treatments with barley planted under conventional tillage out yielding barley directly seeded (Table 4). Although the numbers are different, the tillage affect was similar in 1998 to that of 1997. However, the yield gap between conventional and direct drilling was less in 1998, which is expected considering the drier and warmer conditions of 1998. The gap may have been even less if it were not for the considerable *Rhizoctonia* infection in the direct drilled plots.

b. There was no tillage x variety interaction for grain yield nor any other trait measured. Whereas, there are some differences in ranking of the varieties between conventional and direct seeding, they are not statistically significant. This means that high ranking varieties under conventional tillage are also high ranking under direct seeding (Table 5). This was also found in 1997.

c. Heading date was the only other trait affected by tillage treatment, but although the difference is statistically significant, it is not practically significant (Table 4).

2. Dusty:

a. There were significant tillage effects on grain yield and heading date similar to those found at Ralston (Table 4).

b. Again there were no statistically significant tillage x variety interactions. Therefore, yield rankings were relatively stable between the two tillage treatments (Table 6).

3. Data Combined Over Locations:

a. Significant location effects were detected for all traits except heading date. Yields, test weights, and plant heights were greater at Dusty than at Ralston, as would be expected under the higher moisture conditions at Ralston.

b. The tillage effects and variety responses were similar at both locations. The combined 1998 Ralston/Dusty results were similar to the 1998 individual location results and the 1997 Ralston results. The highest yielding varieties tended to be the same at both locations.

c. There was considerably more foliar disease incidence at Dusty compared to Ralston, but presumably foliar disease occurrence was not influenced by tillage. Although there were barley stripe rust hot spots, they seemed not to be related to tillage. There was some incidence of *Rhizoctonia* at Dusty, but to a lesser extent than at Ralston.

Table 4: Trait means for spring barley varieties grown under conventional tillage or direct seeded conditions at Ralston and Dusty, WA in1998.

Trait (unit)	Ralston		Dusty	
	Conventional	Direct	Conventional	Direct
Grain yield (lb/a)	2538 a	2206 b	3713 a	3486 b
Test weight (lb/bu)	45.0 a	44.8 a	46.1 a	46.0 a
Heading date (Julian d)	163.5 a	163.0 b	163.2 a	162.5 a
Plant height (in)	21.8 a	21.4 a	34.5 a	33.9 b

Means within a **row** followed by the same latter are **not** different according to LSD (α 0.1).

Table 5: Grain yields (with rankings in parentheses) for spring barley varieties grown under conventional and direct seeded conditions at Ralston, WA in 1998.

Conventional tillage		Direct drilled	
Variety	Yield	Variety	Yield
Baronesse	2778 a	WA 9792-90	2448 a
Camelot	2724 ab	Gallatin	2334 ab
WA 9792-90	2706 ab	Stander	2244 bc
Crest	2640 abc	Crest	2244 bc
WA 9339-91	2628 abcd	B1202	2208 bcd
Gallatin	2598 bcd	Chinook	2202 bcd
Harrington	2520 cd	Harrington	2202 bcd
B1202	2514 cd	Camelot	2196 bcd
Steptoe	2484 cd	Baronesse	2190 bcde
Chinook	2466 de	Steptoe	2148 cde
Stander	2310 e	WA 9339-91	2046 de
Colter	2100 f	Colter	2028 e

Means within a **column** followed by the same latter are **not** different according to LSD (α 0.1).

Table 6: Grain yield (with rankings in parentheses) for spring barley varieties grown under conventional and directed seeded conditions at Dusty, WA in 1998.

Conventional tillage		Direct drilled	
Variety	Yield	Variety	Yield
Baronesse	4518 a	Baronesse	4290 a
Camelot	4128 b	Camelot	3972 b
WA 9339-91	3822 c	Crest	3666 c
Crest	3786 cd	WA 9792-90	3654 c
Galatin	3768 cd	Galatin	3522 cd
WA 9792-90	3762 cd	Steptoe	3498 cd
Harrington	3720 cde	Harrington	3450 cde
Chinook	3678 cde	Chinook	3408 def
Steptoe	3600 def	Stander	3276 efg
B1202	3504 ef	B1202	3198 fg
Stander	3390 f	WA 9339-91	3102 g
Colter	2880 g	Colter	2796 h

Means within a **column** followed by the same latter are **not** different according to LSD (α 0.1).

Direct Seed Systems for Grain Legumes – Pursuing Improved Erosion Control, Water Storage, Yields and Profitability

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Direct seeding of grain legumes offers exciting potential benefits in improved soil erosion control, soil quality, yield and profitability. Innovative growers and university scientists have combined efforts to accelerate the development of integrated management systems for the use of direct seeding in the cereal-legume-winter wheat cropping sequence. The following is a brief description of why changes are needed in spring grain legume production practices and preliminary results on these new direct seed systems.

The Need for Change

In the Inland Northwest, soil erosion can be a serious problem in crop rotations with grain legumes followed by winter wheat. Intensive tillage traditionally has been used to bury residue from the previous cereal crop residue and incorporate soil-active herbicides. Today, there are a number of herbicides available that do not require soil incorporation. Another reason for preparing a finely-tilled, low-residue seedbed for spring grain legumes in the past was to facilitate the use of "lifters or pea bars" to pick up the lodged crop on the soil surface at harvest. However, the increasing availability of semi-leafless pea varieties that remain upright and can be harvested with the standard grain header will reduce the need for a smooth, low residue seedbed in the future.

Spring field operations when soils are wet can result in significant soil compaction from tractor traffic and tillage implements. The combination of little or no residue from the previous cereal crop retained on the soil surface after legume planting and the smooth compacted soil from the spring tillage operations can leave legume fields vulnerable to soil erosion during intense rainstorms in the spring and early summer. Spring soil compaction alone also can directly reduce crop yield potential.

Grain legumes produce relatively little crop residue, which is fragile and shatters easily during dry harvest conditions, and decomposes rapidly under moist conditions. Even though growers have made a significant shift towards minimum tillage or direct seeding of winter wheat, surface residue cover from the legume crop alone is often inadequate for erosion control. Without carryover cereal residue preceding the legume crop and the reduction of soil compaction from spring tillage operations for legume establishment, fields with winter wheat after grain legumes can be highly vulnerable to erosion during the critical November to April period, when about 70% percent of the yearly precipitation occurs. Winter wheat is typically seeded later in the fall (October) to reduce the risk of a number of weed, insect and disease problems, and/or because of dry soil conditions earlier in the fall. Consequently, the wheat crop usually over-winters as small plants and provides little erosion protection.

Surface runoff and soil erosion can cause yield losses in both the grain legume and winter wheat crops. Water running off the fields or lost to evaporation is water not stored for grain production.

The greatest impact occurs on upper slopes and ridgetops where yields are most limited by available water. Erosion can reduce current crop yields by loss of plant stands and reduced plant vigor. Soil loss will also reduce future crop yields due to loss of soil fertility, water holding capacity, rooting depth and other soil quality and productivity factors.

Direct Seeding Grain Legumes -- A Promising Solution

Some innovative Northwest growers have been experimenting with direct spring seeding of grain legumes with no prior tillage or with minimum tillage the previous fall. To build upon their efforts, beginning in 1996, a 3-year research project by scientists from University of Idaho and Washington State University was initiated to assist growers in developing integrated management systems for direct seeding of grain legumes. The project is partially supported by collaborative UI and WSU grants from the Pacific Northwest STEEP III (Solutions To Environmental and Economic Problems) conservation farming research program in Idaho, Oregon and Washington. The research is a combination of researcher-managed experiments on university research farms and grower fields, and grower-managed field experiments with their field-scale equipment.

In direct spring seeding of grain legumes, integrated crop and pest management systems for grain legumes must optimize yield, quality and residue production and minimize soil compaction. In addition, winter wheat planting systems must then continue to retain surface residue from the legume and previous cereal crops, and maintain soil physical conditions for effective water infiltration. The overall goal is to improve erosion control, yield potential and profitability in the cereal - legume - winter wheat rotational cycle.

Rotation Consideration -- An important point to keep in mind is that direct seeding / minimum tillage establishment of grain legumes will be much more successful in a crop rotation of three years or longer, such as winter wheat-spring cereal-legume, than in a 2-year winter wheat-legume rotation. The additional year of spring crop, or a winter non-cereal crop, in the rotation is very important in reducing the potential for soilborne diseases and winter annual grass weeds that can be problems under direct seed systems in a 2-year rotation.

This article primarily focuses on 1997-1999 grower field trials comparing spring pea production under direct seeding and other tillage and residue management systems. Preliminary results from other related university trials are available in the 1998 STEEP III Research Progress Report (available on the Internet at http://pnwsteep.wsu.edu or contact Roger Veseth (208-885-6386 or e-mail rveseth@uidaho.edu).

Grower On-Farm Trials

Nine on-farm tests are being conducted during 1996-99 to evaluate spring pea establishment in a cereal - pea - winter wheat rotational sequence under direct seeding compared to more intensive tillage and residue management practices. These are large-scale trials established and managed by collaborating growers with their field equipment. All the trials are being conducted for a 2-year period beginning in the fall after harvest of a spring or winter cereal, through a pea crop and the subsequent winter wheat crop. Nearly all the trials compare a spring direct seed system without prior tillage with some type of fall minimum tillage and direct seeding in the spring without any spring tillage. Some of the trials included additional tillage and residue management treatments to address specific grower's interests and equipment available. All trials have four replications of each treatment and individual plots range from 30 to 50 feet wide and 700 to 1,500 feet long. Surface residue evaluations were conducted after fall tillage of the cereal crop, before and after pea planting, after pea harvest and after winter wheat planting. Other data collection included pea plant stand and yield, and finally winter wheat yield.

Growers involved in the on-farm trials include: Wayne Jensen - Genesee, ID; Nathan and Steve Riggers - Nezperce, ID; Eric Hasselstrom - Winchester, ID; Randy and Larry Keatts - Lewiston, ID; Art Schultheis - Colton, WA; Richard Druffel and Sons - Pullman, WA; Larry Cochran - Colfax, WA and Bob Garrett - Endicott, WA. The results of two grower on-farm trials will be briefly highlighted in the article.

Nathan and Steve Riggers - Nezperce, ID -- Four tillage and residue management systems were compared following a 65 bu/A hard red spring wheat crop west of Nezperce, ID in a 24- to 26-inch rainfall zone (Table 1). Treatments included: 1) Direct Spring Seed; 2) Spring Burn - Direct Spring Seed; 3) Fall Disc - Direct Spring Seed; 4) Fall Moldboard Plow - Spring Cultivate - Seed

The two treatments with overwinter stubble received a late October application of Roundup. In early April, all treatments except the plow treatment received a second Roundup application about 2.5 weeks before planting. All treatments were seeded with a Flexi-Coil 5000 no-till hoe air-seeder on May 4 with Karita peas, a semi-leafless variety. All the plots were harrowed with a tine harrow after seeding. All treatments received separate post-emergence applications of Basagran and Assure II. Winter wheat was direct seeded in the fall with the same Flexi-Coil 5000 no-till hoe airseeder.

Table 1. Comparison of four tillage and residue management practices following 1997 hard red spring wheat through 1998 spring pea and 1999 winter wheat crops, Nathan and Steve Riggers, west of Nezperce, ID - 24- to 26-inch rainfall zone.

Fall and spring treatments before 1998 spring pea crop	Post-Pea planting residue cover	Spring pea emergence	Pea yield	Post-pea harvest residue cover	Post-winter wheat planting residue cover
	%	plants/ft^2	lbs/acre	---------%---------	
Spring Direct Seed	72 a	6.7	2435 a	94 a	60 a
Spring Burn - Spring Direct Seed	10 c	6.2	2208 b	82 b	32 c
Fall Disc - Spring Direct Seed	45 b	7.0	2313 ab	90 a	47 b
Fall Plow-Spring Cultivate-Seed	6 c	7.0	1955 c	75 c	28 c
LSD (5%)	10	NS	166	5	6
C.V. (%)	19.7	10.5	4.6	3.7	8.7

Values within the same column that are followed by same letters are not significantly different at the 95% confidence level.

Residue groundcover levels and pea yield was highest in the non-burn, direct seed systems (Table 3). Surface residue after pea and winter wheat planting were highest in the non-burn, direct seeded pea treatments at 72 and 60%, respectively. Pea emergence was not significantly different among the treatments, but lower than expected because the low seed lot germination (<85%) was not known at planting. Direct seed pea yield was significantly higher than burn and plow treatments, with yields in the trial increasing with increasing surface residue levels.

Art Schultheis - Colton, WA -- Two tillage systems were compared for establishing a 1998 spring pea crop following a 90 bu/A 1997 winter wheat crop just northwest of Colton in a 20- to 22-inch annual rainfall zone (Table 2). Previous rotation crops were lentils in 1996 and spring barley in 1995. Treatments include: 1) Fall Disc-Subsoil - Spring Direct Seed - fall (1997) John Deere disc-ripper - spring harrow - direct seed; and 2) Spring Direct Seed. The winter wheat stubble was flailed after harvest when the residue was dry. Roundup was applied on the direct seed treatments in the fall and on both treatments in the early April. The trial was seeded in late April to Columbia pea with a Flexi-Coil single-disc air seeder. The disc-rip treatments were harrowed after seeding. Basagran and Thistrol were applied post emergence to the disc-rip treatments only (no weeds observed at that time on the direct seed treatments). Assure II was applied to both treatments for grass weed control. Winter wheat was direct seeded with a John Deere 750 single disc no-till drill in the fall.

Direct seeding provided more residue groundcover and better soil erosion protection in both the pea and winter wheat crops. The percent residue cover was significantly higher after planting pea and winter wheat, 96 vs. 19 and 84 vs. 41, respectively. Pea plant stands and yields were not significantly different.

Table 2: Comparison of tillage practices following a 1997 soft white winter wheat crop through 1998 spring pea and 1999 winter wheat crops. Art Schultheis, Colton, WA - 20- to 22-inch annual rainfall zone.

Fall and spring treatments before 1998 spring pea crop	Pre-plant residue cover	Post-plant residue cover	Spring pea emergence	Spring pea yield	Post-harvest residue cover	Post-winter wheat planting residue cover
	----------%----------		plants/ft^2	lbs/acre	----------%----------	
Fall Disc-rip - Spring Direct Seed	37 b	19 b	13.8	2409	81 b	41 b
Spring Direct Seed	100 a	96 a	14.2	2404	98 a	84 a
LSD (5%)	4	5	NS	NS	9	7
C.V. (%)	3.1	5.3	6.1	1.9	5.7	6.1

Values within the same column that are followed by same letters are not significantly different at the 95% confidence level.

Preliminary Conclusions from the Large-Scale Direct Seed Pea Trials

All of the nine large scale field trials currently underway demonstrate that direct seeding of spring peas after cereals can significantly increase surface residue retention for erosion control and water storage through the cereal - grain legume - winter wheat rotation compared to more intensive tillage systems that begin with fall tillage. In addition, pea stand establishment and yield with direct seeding were either not significantly different or greater than with fall tillage. Spring direct seeding also resulted in the higher pea test weight in five of the 1998 direct seed pea trials, although differences were not always statistically significant. This could indicate that a higher level of soil water may be present at grain filling than under more intensive tillage systems. Yield of winter wheat will be compared in the second year of these the field trials in 1999. In the first three project trials completed through the second year with winter wheat harvest, there were no significant differences in winter wheat yield due to the tillage and residue management operations evaluated for grain legume establishment. Economic comparisons have also not yet been completed, but production costs may be reduced with spring direct seeding by eliminating a number of tillage operations.

Other Project Trials Underway

There are several other studies underway that address related management options in direct seed systems for the cereal - grain legume - winter wheat sequence as part of this STEEP III project. The results of these studies will be reported later when the data are available.

1) Residue Production and Durability – Stephen Guy, UI Crop Management Specialist, is leading studies at the UI Kambitsch Research Farm to evaluate differences in residue production between spring wheat and spring barley as the cereal crop preceding the grain legume and differences in residue production between pea and lentil and differences between varieties of each legume crop. In addition to residue production, he is looking at the durability of residue from the spring cereals and legume crops through different tillage practices for establishing the subsequent crops. Similar to the grower on-farm trials, large scale trials are also underway at the Kambitsch Research Farm to compare the effects four tillage systems for establishing spring pea following spring cereals.

2) Herbicide Options – Donn Thill, UI Weed Scientist, is evaluating the relative effectiveness of different herbicides for pre-plant or post-emergence applications on peas under direct seeding and other tillage systems. In addition, he is evaluating herbicide crop safety and soil carryover effects on the following winter wheat crop. Joe Yenish, WSU Extension Weed Scientist, is evaluating these issues at Washington locations and is also evaluating fall versus spring applications of a preplant herbicide for direct seed grain legumes.

3) Fertility – Tim Fiez, WSU Extension Soil Fertility Specialist, is researching the effects of applying 20 lb/acre nitrogen, phosphorus and sulfur (N, P_20_5 or S) fertilizer alone or in all combinations at pea planting under direct seeding and other tillage systems. These trial have been established across the grower large-scale trials. Fertilizer applications have generally not resulted in pea yield increases from under conventional tillage in the region. It is not known if they will respond to fertilizer applications under the new soil and residue environments of direct seed systems.

4) Soil Water Storage and Crop Use – John Hammel, UI Soil Scientist, is evaluating the relative water storage and use of grain legume under direct seed systems compared to more intensive tillage systems.

NW Direct Seed Cropping Systems Conferences Provide Technology Access

Roger Veseth, WSU/UI Extension Conservation Tillage Specialist

Interest in direct seeding and more intensive cropping is rapidly growing across the Northwest and worldwide. Here in the Northwest, about 900 growers and Ag support personnel attending each of the first two Northwest Direct Seed Cropping Systems Conferences in Pasco, WA in 1998 and Spokane, WA in 1999. That is a dramatic increase from the 200-350 attending similar PNW conservation tillage conferences over the past 20 years. The 3rd Direct Seed Cropping System Conference and Trade Show is scheduled for Jan. 4-6, 2000 at the Pendleton Convention Center in Pendleton, OR.

These Conferences help provide NW growers with opportunities to learn about the latest research and technology developments and experiences with direct seeding and more intensive crop rotations from around the Northwest and the world. If you missed the Conferences, you can have the next best thing to being there....professional videos and detailed Conference Proceedings. The entire Proceedings, plus descriptions of topics and speaker covered in each video and video order forms for each year are accessible on the Internet (http://pnwsteep.wsu.edu).

We are entering an exciting new era of crop production across America and around the world. There's been a phenomenal increase in the use of direct seeding systems and more intensive crop rotations in the last few years. These changes are being driven by a number of factors including: increased global market competition and the need for improved profitability, a greater awareness about the soil quality and productivity benefits of direct seeding versus detriments of intensive tillage, increased grower and public concern about cropland soil loss by water and wind erosion, and (in the U.S.) new flexibility in crop rotations under the 1996 Farm Program.

The following are brief summaries of the 1998 and 1999 Northwest Direct Seed Cropping Systems Conferences and the videos and Proceedings that are available. Preliminary plans for the 2000 Conference are also highlighted.

1998 Northwest Direct Seed Intensive Cropping Conference

Nearly 900 Northwest growers and Ag advisers attended the first Northwest Direct Seed Intensive Cropping Conference on January 7-8, 1998 in Pasco, WA. The Conference featured 48 speakers, including 16 grower from across the Northwest, Canada and Australia. It was organized as a service to Northwest growers by the PNW STEEP III (Solutions To Environmental and Economic Problems) program, a cooperative research and educational effort on conservation tillage systems through the University of Idaho, Oregon State University; Washington State University and the USDA-Agricultural Research Service. The Conference was co-sponsored by 14 Ag support companies. It also included 11 PNW and state grower associations and Ag support groups as Conference Cooperators.

The 48 Conference speakers were organized into 7 in-depth Focus Sessions from 2 to 4 hours in length. These include:

1) International and National Trends and Experience with Direct Seeding to Improve Profitability, Global Competitiveness and Resource Protection
2) Alternate Crops for Direct Seeding Systems in the Dryland Inland Northwest
3) Advances in Direct Seed Intensive Cropping Systems in the Inland Northwest -- Low and Intermediate Rainfall Zones
4) Advances in Direct Seed Intensive Cropping Systems in the Inland Northwest -- Higher Rainfall/Annual Cropping Regions
5) New Industry Developments in Direct Seeding Equipment (12)
6) Direct Seeding Impacts on Soil Quality and Production Potential
7) Grower Drill Modification/Fabrication for Direct Seeding Under Northwest Conditions

1998 Conference Proceedings – The detailed 150-page Conference Proceedings can be accessed through the Internet site mentioned above. Print copies are also available for $10 (including mailing) from: NW Direct Seed Conference, P.O. 2002, Pasco, WA 99320, FAX 509-547-5563, phone 547-5538, e-mail: Heather Filbin <maurer@owt.com>. The Proceedings includes papers from 36 of the Conference speakers, not including the 12 drill company representative that spoke at the Conference. An address and phone listing of the 12 direct seeding equipment companies participating in the conference will also be included with the Proceedings.

1998 Conference Videos – Videotapes of the seven 2- to 3-hour Conference Focus Sessions are available for purchase ($15 each) or loan (in the Northwest). More than 100 sets of the tapes were sold within three months after the Conference. Complete descriptions of the presentations and speakers on each the 7 videos and a copy of the video order form can be accessed through the Internet site or call the WSU Crop and Soil Sciences Dept. Extension office at 509-335-2915 (FAX 335-1758; e-mail: winterowd@wsu.edu).

1999 Northwest Direct Seed Cropping Systems Conference and Trade Show

Over 920 growers and Ag support personnel attended the Conference. It was organized as a service to growers by the Pacific Northwest STEEP III program and co-sponsored by 12 Ag support companies, in cooperation with 11 PNW grower organizations, conservation district associations and other Ag support groups and agencies. The Conference featured 37 speakers, including 14 researchers, 7 industry representatives and 16 growers from across the Pacific Northwest, Northern Great Plains, Canada, Argentina, and Brazil. There were 7 in-depth Focus Sessions on a variety of topics including:

1) International and National Experiences with Direct Seed Cropping Systems
1) Agronomics and Economics of Alternate Crops and Rotations for Direct Seeding
2) Managing to Optimize Soil Quality Benefits from Direct Seed Cropping Systems
3) Northwest Grower Experiences with Cropping Systems and Equipment for Direct Seeding
4) Making Sense of the Row Spacing Debate
5) Direct Seed Grain Legume -- Management Systems for Expanding Northwest Production Opportunities
6) Economics and Strategies for the Transition to Direct Seed Cropping Systems

Conference Proceedings -- The 225-page Proceedings provides a detailed summary of the 37 speaker presentations. The entire Proceedings can be accessed on the Internet site. Print copies are also available for $10 (including mailing) payable to NW Direct Seed Conference, ATTN: Heather Filbin, P.O. 2002, Pasco, WA 99320, phone 547-5538, FAX 509-547-5563 or e-mail (Heather Filbin <maurer@owt.com>).

Digital-Quality Videos – The seven Focus Sessions, ranging from 1 hour to 6 hours, were videotaped with a high-quality digital camera. A series of 10 videotapes are available on loan (in the Pacific Northwest) and for sale at $15 each. A detailed descriptions of topics and speakers included on each video are available on the Internet site, or contact the Cooperative Extension Office, Crop and Soil Sciences Dept., P.O. Box 646420, Washington State University, Pullman, WA 99164-6420, phone 509-335-2915, FAX 335-1758, or email (winterowd@wsu.edu).

2000 Northwest Direct Seed Cropping Systems Conference and Trade Show

The 3rd Northwest Direct Seed Cropping Systems Conference and Trade Show is scheduled for January 4-6, 2000 at the Pendleton Convention Center in Pendleton, OR.. The Conference program will begin at 1:00 p.m. Tuesday January 4 and adjourn at noon Thursday January 6. Four half-day Focus Session tentatively include: 1) Residue Management; 2) Economics; 3) Pest Management; and 4) Drills and Equipment. Speakers tentatively include growers, researchers, and industry representatives from across the Northwest, U.S., Canada, Australia, and South America.

As with the past two Conferences, the 2000 Conference is being organized as a service to Northwest growers through the Pacific Northwest STEEP III conservation farming research and educational program and will be co-sponsored by Ag support companies in cooperation with PNW grower organizations, conservation district associations and other Ag support groups and agencies.

Conference Internet Home Page: A direct Conference Internet home page (http://pnwsteep.wsu.edu/conf2k) will continually be updated with all the information about the Conference program, Trade Show, registration, motels, proceedings, and so on.

Phone / Mail / Fax / E-mail Information Sources: To receive a copy of the Conference brochure, Sponsorship / Trade Show prospectus or other Conference information when it is available, call the NW Direct Seed Conference office at 509-547-5538, FAX 547-5563, E-mail (maurer@owt.com). You can also contact Don Wysocki, Conference Chair and OSU Extension Soil Scientist, at 541-278-4396, FAX 278-4188; e-mail (Donald.Wysocki@orst.edu).

Economics of No-till Wheat and Barley Production on Farms in The 8 to 13 Inch Rainfall Area of Eastern Washington

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For over a century, farmers in regions of the Pacific Northwest (PNW) receiving less than 18 inches of annual rainfall have used the summer fallow/winter wheat cropping system to effectively stabilize crop yields and annual income in a challenging climatic environment. Unfortunately, conventional tillage summer fallow and winter wheat seeding leave fields vulnerable to serious wind erosion. Blowing dust removes valuable topsoil from farmers' fields and causes offsite problems for the general public. Chem-fallow and continuous no-till hard red spring wheat (HRSW) offer potentially effective ways to combat wind erosion, but little research has been devoted to the long-term agronomic and economic viability of these systems. The 18 to 22 inch rainfall zone of the Palouse has benefitted from long-term, no-till and minimum tillage cropping systems research at the 1974-87 University of Idaho STEEP trials near Moscow, ID and the 1986-94 USDA IPM trials near Pullman, WA. The only comparable no-till farming systems research in the low rainfall zone is the trials at Ralston, WA for which only three years of data are available. Despite the lack of no-till research in the low rainfall region, individual growers have tried no-till winter wheat, spring barley, and spring wheat production. Some have reported successful results at direct seeding conferences and local field days. Given the lack of information on no-till in the low rainfall zone, a systematic review of the economic results of no-till farmers in the region would be useful to other farmers contemplating the practice. This paper reports the results of economic case studies for four no-till wheat and barley growers in the 8- to 13-inch rainfall zone of eastern Washington.

Sample and Procedures

Although all four no-till growers farmed within the 8- to 13-inch rainfall zone, their soils and annual precipitation varied considerably which caused crop rotations and yields to differ. Two of the no-till farmers followed a winter wheat-spring barley-fallow rotation. The other two grew continuous no-till HRSW. The four growers operated farms ranging from 1,000 to 8,000 acres. There was considerable variation in the percentage of land rented, the age and type of machinery used, and other business characteristics.

Researchers collected initial information on each grower's no-till production practices in on-farm personal interviews lasting from one and a half to three hours. Follow-up interviews and telephone calls were made as necessary to complete and verify data. The no-till farmers provided information on the timing and composition of their farming operations; the purchase price, purchase date, size, age, annual repairs, and hours of annual use of machinery; speed and fuel use for each operation; type and rates of inputs used; fixed costs such as land costs, taxes, insurance, and overhead; and any other costs or special practices. Growers also estimated their five-year average crop yields under no-till. All machinery costs were converted to consistent 1998 dollars and standard procedures for estimating overhead and miscellaneous costs were used. Average agricultural engineering rates were used for replacing any missing machinery data. The data were then used to prepare an enterprise budget for each crop for each farmer using the Cooperative Extension Enterprise Budget Generator in the WSU Department of Agricultural Economics.

Results

Tables 1, 2, and 3 report winter wheat, spring barley, and HRSW average yields and estimated production costs per acre and per bushel for the four no-till growers and for revised "typical" conventional tillage budgets for the area prepared by Cooperative Extension staff.

The no-till winter wheat total costs/bu for growers J and L are $2.66 and $3.10, with the Extension conventional tillage estimate falling in the middle at $2.96 (Table 1). All three total costs, which include a wage for the operator and market returns for land and machinery as well as other costs, compare favorably to the 1993-97 average market price for soft white winter wheat of $3.72/bu.

No-till spring barley total costs for growers J and L also "straddle" the Extension conventional tillage cost with the three estimates ranging from $58.35/ton to $75.70/ton (Table 2). Both growers would realize a profit given the 1993-97 average barley price of $85/ton. Grower J in a 13-inch rainfall area enjoys a yield and cost of production advantage over farmer L in a 11-inch rainfall area for both winter wheat and spring barley.

Farmer I grows continuous no-till HRSW in a 11-inch rainfall area averaging 38.5 bu/ac. Farmer K averages 31 bu/ac in an 8-inch rainfall area (Table 3). The higher rainfall farmer produces HRSW at $3.85/bu versus $4.70/bu for the farmer in the drier area. Higher crop yields for farmer I account for the difference. Total production costs per acre for the two farmers are very similar. Total costs/bu for farmer I falls considerably below, and for farmer J just above, the 1993-97 average HRSW price of $4.50/bu. Extension's conventional tillage HRSW total cost estimate of $3.25/bu falls considerably below the costs of farmers I and K and the average HRSW price. The Extension budget assumes a similar yield of 35 bu/ac, but about $33/ac less total costs than the average of the farmers. The estimates for farmers I and K are based on several years individual experience as successful HRSW growers in the area. The Extension HRSW cost estimate is based on the collective judgement of a panel of growers and Extension personnel whose experience with this relatively new crop for this area is not known.

The case studies of four growers indicated that no-till production of a winter wheat-spring barley-fallow rotation in the 11 to 13 inch rainfall region of eastern Washington could be profitable assuming long-run average crop prices. Two growers also produced continuous no-till HRSW at or near breakeven costs. Of course, it is not possible to generalize the results from these four no-till growers to all growers contemplating no-till production in the low rainfall regions of the PNW. Every farm faces unique resource and business conditions. However, these case studies show that promising economic results are possible with no-till with proper management.

Table 1. Winter Wheat - Summer Fallow Yields and Costs of Production for Two No-Till Farmers and an Extension Conventional Tillage Budget, 11 to 13 inch Rainfall Zone.

Farmer	Yield (bu/ac)	Variable Costs ($/2 ac)	Fixed Costs ($/2 ac)	Total Costs ($/2 ac)	Variable Costs ($/bu)	Total Costs ($/bu)
J	75.00	77.54	121.63	199.17	1.03	2.66
L	42.50	31.96	99.92	131.88	0.75	3.10
Av.	58.75	54.75	110.78	165.53	0.89	2.88
Ext.[a]	52.00	38.08	115.78	153.86	0.73	2.96

Table 2. Spring Barley Yields and Costs of Production for Two No-Till Farmers and an Extension Conventional Tillage Budget, 11 to 13 inch Rainfall Zone.

Farmer	Yield (ton/ac)	Variable Costs ($/ac)	Fixed Costs ($/ac)	Total Costs ($/ac)	Variable Costs ($/ton)	Total Costs ($/ton)
J	1.85	85.54	54.50	140.04	46.24	75.70
L	1.62	51.38	43.14	94.52	31.72	58.35
Av.	1.75	68.46	48.82	117.28	38.98	67.03
Ext.[b]	1.25	94.97	52.91	147.88	75.98	118.30

Table 3. Hard Red Spring Wheat Yields and Costs of Production for Two No-Till Farmers and for an Extension Conventional Tillage Budget, 8 to 11 inch Rainfall Zone.

Farmer	Yield (bu/ac)	Variable Costs ($/ac)	Fixed Costs ($/ac)	Total Costs ($/ac)	Variable Costs ($/bu)	Total Costs ($/bu)
I	38.50	71.30	77.03	148.33	1.85	3.85
K	31.00	81.07	64.76	145.83	2.62	4.70
Av.	34.75	76.19	70.90	147.08	2.24	4.28
Ext.[a]	35.00	67.65	46.03	113.68	1.93	3.25

[a] Hinman and Esser. 1999 Enterprise Budges. Adams County, WSU Ext. Bul. (forthcoming).

[b] Painter et al. 1995 Crop Rotation Budgets for Western Whitman County, Washington. Cooperative Extension Bulletin EB 1795, Washington State University, Pullman, WA, 1995.

Profitability Analysis For 1995-1998 Results Of Wheat-fallow Cropping at Lind, Washington

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This report presents average profitability results over 1995-98 of a soft white winter wheat (SWWW)-fallow cropping experiment at the Lind, Washington Research Station. Traditional summer fallow tillage is compared with minimum and delayed minimum tillage fallow. Long run annual precipitation at the site averages 9.44 inches, but has been 12.76 inches during 1995-98.

The conventional winter wheat/tillage fallow system in this region has provided advantages of income stabilization, moisture conservation, economical tillage weed control, and efficiencies in seasonal labor and machinery use. However, conventional tillage summer fallow can leave the soil susceptible to wind erosion, especially after low crop production years. Wind erosion not only harms the grower by removing valuable topsoil, but blowing dust causes problems for the general public. An important objective of the Lind research is to identify winter wheat/fallow systems which preserve the economic and agronomic advantages of this time tested system while better protecting soil and air quality.

Fallow Tillage Treatments

The minimum and delayed minimum tillage systems use herbicides, when needed, for post-harvest control of Russian thistle rather than sweep tillage as in the conventional system. The delayed minimum tillage delays primary tillage from March until mid-May or June and averages one less rodweeding per fallow cycle than the other two systems. Paired parcels of land were used so that both crop and fallow portions of the experiment appear each year.

Both minimum tillage systems easily maintained the minimum 350 lbs/acre of surface residue at the end of a fallow cycle necessary to preserve eligibility for government transition payments. These surface residue levels were not attainable using conventional tillage after low crop production years. Both minimum tillage systems increased over-winter soil water storage efficiency, surface residue retention, and surface cloddiness compared to conventional tillage.

Profitability Comparisons

Table 1 shows production costs for each tillage management system. These costs are based on the actual input rates and sequence of field operations at the Lind research plots. The cost calculations assume machinery sizes and types typical of farms in the study area. Variable and total costs were similar for the three systems; costs differed over systems by generally less than $4 per rotational acre. Total costs include market rates of return on the farmer's land, machinery, and labor. Table 1 also reports two "profit" measures for each cropping system: net returns over variable costs and net returns over total costs. These net returns are based on the calculated costs in Table 1, the 1995-98 average Lind experiment yields (see Table 2), and the utilized 1993-97 average soft white wheat price of $3.92/bu and (protein-adjusted) hard red spring wheat price of $5.10/bu. Hard red spring wheat (HRSW) was planted in the spring of 1995 at Lind because seed-zone moisture was not sufficient to plant winter wheat in September 1994. It is assumed that inadequate fall moisture or winter kill will occur one year out of every five so the HRSW net returns were weighted 20% and the SWWW net returns were weighted 80% in computing net returns for each of the three systems in Table 1.

The results in Table 1 show that minimum tillage, delayed minimum tillage, and conventional tillage fallow/winter wheat systems at Lind produced statistically equal net returns over total costs during 1995-98. The statistical comparisons of net return means were based on 16 observations each (four replications per year over four years). The three tillage systems came within only $1.84 to $4.47 per acre of covering full costs, including the farmer's wage and market returns to land and machinery. Readers are cautioned that these results may not apply to individual farmers in the region whose costs and yields differ from those for the Lind Research Station trials.

Growers should use net returns over total costs to make long run production decisions, but they may use net returns over variable costs for short run decisions. Net returns over variable costs reported in Table 1 reveal close results similar to those for net returns over total costs. The delayed minimum tillage system had significantly lower net returns over variable costs compared to the other two systems, but its net returns were still only $4 lower per rotational acre.

The net returns results in Table 1 are of course conditional upon the long run average crop prices and 4-year average Lind experiment crop yields. To shed some insight on the impact of variable crop prices and yields on profitability of winter wheat/fallow systems in this area, Table 3 reports price and yield sensitivity analysis for returns over variable costs for the minimum tillage system. The results show negative returns over even variable costs for all yields below 40 bu/ac when soft white winter wheat prices fall below $3/bu. Readers are cautioned that these sensitivity results are dependent upon the utilized minimum tillage variable costs from the Lind experiment of $62.56 per rotational acre (Table 1).

Conclusions

The economic analysis of the 4-year Lind cropping systems experiment presents a welcome "win-win" solution for farmers and soil and air quality. The minimum tillage and delayed minimum tillage fallow/winter wheat systems averaged statistically equal net returns over total costs with the conventional tillage system. With a $2.63 per acre average profit advantage, the minimum tillage system fell just short of being significantly more profitable than the traditional conventional tillage system. These results present a potential opportunity to save topsoil, to improve air quality, and to maintain or improve farm profitability.

Previous research has indicated that residents of urban areas on the Columbia Plateau may be willing to pay for clean air programs; however, it would involve fewer political and administrative delays by using educational programs to promote practices like these conservation fallow tillage systems which do not require public subsidies to be competitive.

Table 1. Average Revenue, Cost, and Net Returns ($/rotational acre) by Tillage System for the Lind Experiment, 1995-98

Tillage System	Rev/Ac	Cost/Ac		Net Returns Over Cost	
		Variable	Total	Variable	Total
Conventional Tillage	111.16	59.97	115.63	51.20 a	-4.47 a
Minimum Tillage	114.45	62.56	116.29	51.89 a	-1.84 a
Delayed Minimum Tillage	108.75	61.17	112.27	47.58 b	-3.52 a

Notes:
1) Long run hard red spring wheat (HRSW) price at experiment protein level of 15.9% is $5.10/bu.
2) Long run soft white winter wheat (SWWW) price is $3.92/bu.
3) All calculations based on rotational acre (½ acre wheat, ½ acre summer fallow).
4) All calculations based on weighted average of 80% SWWW and 20% HRSW.
5) LSD=3.11; results within a column followed by the same letter do not differ statistically at the 0.05 level.

Table 2. Annual Average Plot Yields (bu/ac) by Cropping System, Lind Experiment, 1995-98

Tillage System	1995	1996	1997	1998	Avg.
Conventional Tillage	26.67	52.40	76.38	57.88	62.22
Minimum Tillage	28.45	55.90	77.42	57.90	63.74
Delayed Minimum Tillage	26.58	55.42	73.43	53.28	60.71

Note:
1) 1995 is hard red spring wheat; 1996-1998 is soft white winter wheat. Avg. is the soft white winter wheat average for 1996-1998.

Table 3. Price and Yield Sensitivity Results for Returns over Variable Cost ($/Rotational Acre) for Minimum Tillage Soft White Winter Wheat/Summer Fallow System with Variable Cost of $62.56/Acre, Lind Experiment, 1995-98

Yield	Price ($/bu)					
(bu/harvested acre)	2.50	3.00	3.50	4.00	4.50	5.00
25	-29.40	-23.15	-16.90	-10.65	-4.40	1.85
30	-23.15	-15.65	-8.15	-0.65	6.85	14.35
35	-16.90	-8.15	0.60	9.35	18.11	26.86
40	-10.65	-0.65	9.35	19.36	29.36	39.36
45	-4.40	6.85	18.11	29.36	40.61	51.86
50	1.85	14.35	26.86	39.36	51.86	64.36
55	8.10	21.86	35.61	49.36	63.11	76.86
60	14.35	29.36	44.36	59.36	74.36	89.36
65	20.61	36.86	53.11	69.36	85.61	101.86
70	26.86	44.36	61.86	79.36	96.86	114.36

Economics of No-till Winter Wheat on Farms in The 19 to 22 Inch Rainfall Zone of The Pacific Northwest

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Despite the dominance of tillage in Pacific Northwest (PNW) dryland farming, a small but visible minority of growers in the region appear to have used no-till with economic success. Some of these growers have spoken at farm meetings and described their methods to others. For example, no-till farmers shared their experiences with over 800 growers and other interested individuals at both the 1998 and 1999 STEEP Direct Seeding Conferences.

Economic evaluations of no-till research experiments have been conducted over the past two decades. However, no long-term 100 percent no-till research trials in the PNW appear to have matched the success reported by a few individual no-till farmers. This provides justification for closely examining and documenting the cultural practices, production costs, and economic returns of PNW farmers who have used no-till over an extended period of time. This paper reports the results for no-till winter wheat production from detailed case studies of six long term, no-till farms in the 19 to 22 inch rainfall zone of eastern Washington and northern Idaho. A more complete report, including results for no-till spring crops, will be published in a forthcoming WSU Cooperative Extension Bulletin.

Sample and Procedures

Although all six no-till growers farmed within the annual cropping zone of the PNW, their soils and microclimates varied considerably which caused crop yields and production practices to differ. Five of the no-till farmers generally followed a winter wheat-spring wheat-pea or lentil rotation. The other followed a winter wheat-spring barley-spring wheat rotation. The farmers reported five-year average wheat yields from 72 to 110 bu/ac with an average of 83 bu/ac. Farm size varied from 1,400 to 4,500 acres. There was considerable variation in the percentage of land rented, the age and type of machinery used, and other business characteristics.

Researchers collected initial information on each grower's no-till production practices in on-farm personal interviews lasting from one and a half to three hours. Follow-up interviews and telephone calls were made as necessary to complete and verify data. The no-till farmers provided information on the timing and composition of their farming operations; the purchase price, purchase date, size, age, annual repairs, and hours of annual use of machinery; speed and fuel use for each operation; type and rates of inputs used; fixed costs such as land costs, taxes, insurance, and overhead; and any other costs or special practices. Growers also estimated their five-year average crop yields under no-till. All machinery costs were converted to consistent 1998 dollars and standard procedures for estimating overhead and miscellaneous costs were used. Average agricultural engineering rates were used for replacing any missing machinery data. The data were used to prepare an enterprise budget for each crop for each farmer using the Cooperative Extension Enterprise Budget Generator in the WSU Department of Agricultural Economics.

Results

Table 1 reports winter wheat average yields and estimated production costs per acre and per bushel for the six no-till growers and for an updated "typical" eastern Whitman County, WA conventional tillage budget prepared by Cooperative Extension staff. All six no-till growers' winter wheat production costs are impressively low and remarkably uniform. Total costs/bu range from $2.52 to $2.93 compared to $2.95/bu for the typical conventional tillage budget. The average no-till total production costs of $2.66/bu beats the 1993-97 average market price for soft white winter wheat of $3.72 by more than a dollar. Total production costs include a wage for the farmer's labor and a fair market return to land and machinery investment, as well as other costs.

As expected, farmers with higher total costs per acre tend to produce higher crop yields. For example, farmer B, whose farm has favorable soils and climate, spends about $50/ac more to produce winter wheat than the other no-till growers, but his yields are also 30 bu/ac higher than the other growers.

This research revealed that the production costs/bu for winter wheat were substantially lower than those for spring crops. For example, total production costs for spring wheat averaged $3.40/bu for the five no-till growers who grew spring wheat. This is not surprising because winter wheat has long been the most productive and profitable crop in the Palouse. It is expected to "carry" more than its share of total rotation production costs in order to "subsidize" less profitable, but agronomically necessary, spring crops.

The impressive cost results in Table 1 raise the question of whether the nonrandom sample of six no-till growers was atypically successful due to personal experience, managerial acumen, or favorable agro-climatic environments. While these growers may be further along on the learning curve than most, they were very humble about failures along the way and claimed to be blessed by no special luck or knowledge. Possibly, the study may have missed or underestimated some costs, or some yields may have been overestimated, thereby understating production costs. However, the uniformity of per bushel costs over the six growers adds support to the estimates.

Finally, readers should recognize that the production efficiency results in Table 1 do not permit any conclusions about the comparative profitability of the six no-till winter wheat growers. Profit comparisons require information on both sides of the economic equation--production costs and marketing performance. For example, it is known that one of the growers in Table 1 with higher production costs forward contracted his 1998 wheat crop for over $4/bu. This grower earned significantly higher profits than others who may have had slightly lower production costs but sold their wheat during 1998 for less than $3/bu.

It is not possible to generalize the results from these six no-till growers to all growers contemplating no-till winter wheat production in the annual cropping region of the PNW. Every farm faces unique resource and business conditions. However, these case studies show that promising economic results are possible with no-till winter wheat production with proper management.

Table 1. Winter Wheat Yields and Costs of Production for Six No-Till Farmers and an Extension Conventional Tillage Budget, 19 to 22 inch Rainfall Zone.

Farmer	Yield (bu/ac)	Variable Costs ($/ac)	Fixed Costs ($/ac)	Total Costs ($/ac)	Variable Costs ($/bu)	Total Costs ($/bu)
A	85	122.20	98.63	220.83	1.44	2.60
B	110	131.99	155.52	287.51	1.20	2.61
C	85	115.77	104.74	220.51	1.36	2.59
D	72	108.03	103.19	211.22	1.50	2.93
E	75	109.81	92.59	202.40	1.46	2.70
F	91	95.55	133.54	229.09	1.05	2.52
Av.	86.33	113.89	114.70	228.59	1.34	2.66
Ext.[a]	75.00	99.60	121.28	220.88	1.34	2.95

[a] Painter, K., H. Hinman, and J. Burns. 1995 Crop Rotation Budgets for Eastern Whitman County, Washington. Washington State University, Cooperative Extension Bulletin EB1437, Pullman, WA, 1995 (revised and updated, 1999).

Profitability Analysis for Ralston Spring Cropping Trials, 1996-1998

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This report presents economic results for the first three years of the Ralston, WA Integrated Spring Cropping Trials. These trials compared the traditional soft white winter wheat/summer fallow cropping system, which dominates the area, with three no-till spring cropping systems: (1) soft white spring wheat/chemical fallow, (2) continuous hard red spring wheat, and (3) hard red spring wheat/spring barley. The wheat/fallow system employed minimum tillage with light disking or standing stubble after harvest and only two rodweedings per summer.

The traditional winter wheat/ fallow system in this region has historically offered advantages in terms of income stabilization, moisture conservation, economical tillage weed control, efficiencies in seasonal labor and machinery use, and consistencies with acreage bases and established yield provisions of pre-1996 farm programs. However, this summer fallow system has conflicted with important air and soil quality concerns. Dust blowing from fallow and/or winter wheat fields reduces air quality over large downwind areas and decreases the long-term soil productivity and sustainability of agriculture in these regions. No-till continuous spring cropping has the potential to greatly reduce soil loss and air pollution from wind erosion. Spring cropping also permits eliminating troublesome winter grass weeds. Local producers have also shown increased interest in annual spring cropping due to increased planting flexibility offered by the 1996 Farm Bill. More research on conservation tillage spring cropping systems is essential before large scale adoption will occur.

Preliminary Economic Results

Annual precipitation during 1996-98 averaged 14.58 inches per year, 27% above the 11.5 inch average for Ralston. The above average precipitation may have contributed to higher yields and costs compared to a "typical" year. For example, higher precipitation may have increased weed competition and herbicide use and may also have induced higher levels of fertilization.

All costs and revenues in this study are presented on a per rotational acre basis; for example, for winter wheat-summer fallow, costs and revenues are computed for one half acre of winter wheat and one half acre of fallow. This correctly portrays the average return per farm acre per year of a grower who has one half of the farm in fallow and one half in winter wheat.

Table 1 presents revenues, costs, and net returns for all cropping systems in the Ralston Project. All costs are based on actual input rates and sequence of field operations used at the trials. All machinery costs are based on typical farm equipment for the Ralston area. The 1993-97 average crop prices and the average yields from the experiment which, with costs, determine the profitability results are presented in Tables 2 and 3. The economic results presented in this study will not generalize to area farms whose costs and yields differ from those at the Ralston research trials. For example, Cooperative Extension staff recently constructed "representative" Adams

County farm budgets for annual hard red spring wheat and winter wheat/fallow which showed lower costs, especially for fertilizer, but higher profits, than those reported in Table 1.

Results of the first three years of the long term Ralston study show that conventional tillage winter wheat/summer fallow had statistically higher returns over total costs by a margin of $19.95 to $27.68 per rotational acre over the three no-till spring cropping systems (Table 1). Conventional winter wheat/fallow (SWWW/fallow) earned -$1.48/rotational acre, nearly breaking even with total costs of production. Total costs include a wage for the operator's labor, a market return for land and machinery, as well as all other costs. SWWW after conventional fallow averaged 73 bu/ac at Ralston during 1996-98, an exceptional yield for this arid region (Table 2). The wet conditions during 1996-98 favored both winter wheat and spring wheat yields.

Continuous hard red spring wheat (cont. HRSW) with actual protein ranked second at -$21.43 returns over total costs per rotational acre. Soft white spring wheat/chemical fallow (SWSW/fallow) ranked third at -$25.54 per rotational acre. Hard red spring wheat/spring barley (HRSW/SB) with actual protein ranked fourth at -$29.16 per acre. Poor barley yields during 1996 substantially reduced this system's profitability (Table 2). Barley yields in this establishment year were hurt by diseases, an early frost, and inadequate management practices.

The conventional SWWW/fallow system also had a statistically significant economic advantage over the spring cropping systems by $7.63 to $40.65 per rotational acre for returns over variable costs (Table 1). Variable costs exclude equipment fixed costs and land costs. The gap between the cont. HRSW and SWWW/fallow was $12 narrower for returns over variable versus total costs. The traditional winter wheat/fallow and the continuous HRSW systems exhibited the highest net returns over variable cost, at $64.40 and $56.73 per rotational acre, respectively. The HRSW/SB ranked third with net returns over variable cost at $41.99 per rotational acre, $15 below the continuous HRSW, while the SWSW/fallow system ranked a distant fourth at $23.75 per rotational acre. The SWSW/fallow system had a narrower advantage in terms of net returns over variable costs because this cropping system has very low fixed costs (variable cost + fixed cost = total cost).

Table 1 reports net returns for the hypothetical situation in which HRSW consistently achieves 14 percent protein. While HRSW at Ralston failed to consistently achieve 14 percent protein during 1996-98, it is useful to examine the added profitability from reaching this goal. With 14 percent protein, the continuous HRSW system would still rank second and net returns improved by about $5 per rotational acre for both net returns measures. HRSW/SB net returns improved by only a dollar.

Table 4 reports continuous HRSW net returns over variable costs for various yield and protein combinations. Gross revenues include HRSW prices adjusted for penalties below 14% protein and premiums above 14% protein. Estimated continuous HRSW variable costs from Table 1 were utilized. Protein levels cause very large differences in net returns. For example, at 45 bu/ac net returns over variable costs increase from $27.35 per acre at 12 percent protein to $70.55 per acre with 15.5 percent protein. Table 4 shows positive net returns over variable costs for all protein levels when yields equal or exceed 40 bushels per acre. However, production costs would likely vary from the constant amount assumed in Table 4 as yields differ markedly from the

Ralston levels. Thus, Table 4 may overstate losses at lower production levels and overstate net returns for higher yield levels.

Conclusions

These three-year results at Ralston show a substantial profitability advantage for the conventional SWWW/fallow system; however, continuous HRSW could have narrowed the net returns over total costs disadvantage to about $15 per acre if 14 percent protein level was consistently achieved. Further research to develop suitable varieties and best management practices for continuous no-till spring wheat and barley should make spring cropping more competitive. Gains in future yields due to soil conservation could also increase the value of the spring cropping, but the payoff is slow for farmers under short term economic pressures. Other work has shown public valuation for clean air, which might justify public cost sharing for producers who adopt air quality cropping systems which protect air quality.

Table 1. Net returns over selected production costs ($/ac/yr) by rotation, 1996-1998 averages, Ralston Trials.

	Rev/Ac	Cost/Ac		Net Returns Over Cost	
Rotation		Variable	Total	Variable	Total
SWWW/ fallow	142.72	78.32	144.20	64.40 a	-1.48 a
SWSW/ chem fallow	115.29	91.54	140.83	23.75 e	-25.54 d
Cont. HRSW					
actual protein	215.68	158.95	237.11	56.73 c	-21.43 c
14% protein	220.21	158.95	237.11	61.26 b	-16.90 b
HRSW/SB					
actual protein	189.33	147.34	218.49	41.99 d	-29.16 e
14% protein	190.44	147.34	218.49	43.10 d	-28.05 e

Notes:
1) SWWW 1993-97 average price= $3.92/ bu.
2) Cont. HRSW actual protein price, 1993-97 average= $4.76/bu.
3) HRSW/ SB actual protein price, 1993 average= $4.81/bu.
5) LSD=3.13; results within a column followed by the same letter do not differ statistically at the 0.05 level.
6) $0.04/bu protein premium for each 1/4% above 14% up to 15.5%; $0.09/bu protein penalty for each 1/4% below 14%

Table 2. Annual Crop Yields and HRSW Protein Levels by Rotation and Year, Ralston Trials

Crop Rotation	1996	1997	1998	Avg.
SWWW (bu/ac): SWWW/ fallow	78.11	64.44	75.89	72.81
SWSW (bu/ac): SWSW/chem fallow	51.00	60.78	64.67	58.82
HRSW (bu/ac): Cont. HRSW	40.05	55.33	40.56	45.31
% protein	13.45	13.00	15.65	14.03
HRSW (bu/ac): HRSW/SB	42.78	55.67	44.11	47.52
% protein	14.20	13.40	14.40	14.00
SB (tons/ac): HRSW/SB	1.03	1.81	1.63	1.49

Note:
1) All wheat yields reflect standard 10% moisture and chaff.
2) All barley yields reflect standard 7.5% moisture and chaff.

Table 3. 1993-97 Average Crop Prices	
SWWW ($/bu)	3.92
SWSW ($/bu)	3.92
HRSW 14% protein ($/bu)	4.86
SB ($/ton)	100.63

Table 4. Hard Red Spring Wheat Net Returns over Variable Costs at Various Protein Levels and Yields, Assuming Variable Costs = $158.95 per Acre.

	Yield (bu/ac)								
% Protein	20	25	30	35	40	45	50	55	60
12	-76.15	-55.45	-34.75	-14.05	6.65	27.35	48.05	68.75	89.45
12.25	-74.35	-53.20	-32.05	-10.90	10.25	31.40	52.55	73.70	94.85
12.5	-72.55	-50.95	-29.35	-7.75	13.85	35.45	57.05	78.65	100.25
12.75	-70.75	-48.70	-26.65	-4.60	17.45	39.50	61.55	83.60	105.65
13	-68.95	-46.45	-23.95	-1.45	21.05	43.55	66.05	88.55	111.05
13.25	-67.15	-44.20	-21.25	1.70	24.65	47.60	70.55	93.50	116.45
13.5	-65.35	-41.95	-18.55	4.85	28.25	51.65	75.05	98.45	121.85
13.75	-63.55	-39.70	-15.85	8.00	31.85	55.70	79.55	103.40	127.25
14	-61.75	-37.45	-13.15	11.15	35.45	59.75	84.05	108.35	132.65
14.25	-60.95	-36.45	-11.95	12.55	37.05	61.55	86.05	110.55	135.05
14.5	-60.15	-35.45	-10.75	13.95	38.65	63.35	88.05	112.75	137.45
14.75	-59.35	-34.45	-9.55	15.35	40.25	65.15	90.05	114.95	139.85
15	-58.55	-33.45	-8.35	16.75	41.85	66.95	92.05	117.15	142.25
15.25	-57.75	-32.45	-7.15	18.15	43.45	68.75	94.05	119.35	144.65
15.5	-56.95	-31.45	-5.95	19.55	45.05	70.55	96.05	121.55	147.05

Note: Assuming $0.04/bu protein premium for each 1/4% above 14% up to 15.5%; $0.09/bu protein penalty for each 1/4% below 14%