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

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

Abstract

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

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

Introduction

The conventional tillage (CT) winter wheat-summer fallow rotation reduces soil organic carbon, exacerbates soil erosion, and is not biologically sustainable (Rasmussen and Parton 1994). Despite these concerns, adoption of alternate cropping systems such as intensive cropping and direct seeding, has been slow due to lack of long-term research on viability of alternate cropping systems in Oregon. Occasional crop failures occurred under long-term conventional intensive cropping studies conducted at the Sherman Experiment Station in the 1940's to the 1960's (Hall 1955, 1960, 1963. But with the advent of new varieties and agronomic practices such as direct seeding, long-term research is needed to evaluate benefits and risks of annual cropping, potential alternate crops, and alternative rotations. The main focus of this work is to establish and maintain long-term experiments that compare the conventional wheat-fallow system with alternate cropping systems and crop management practices such as direct seeding that reduce wind and water erosion. Specific objectives include developing systems that increase residue cover; increase soil organic matter and biological activity; increase water infiltration and available soil moisture; reduce wind and water erosion; reduce soil water evaporation; reduce pests; sustain soil and crop productivity; evaluate the variable costs and crop value of the cropping systems under evaluation; and extend the results to growers. The research is targeted for Agronomic Zones 4 and 5 in north-central Oregon.

Methods and Materials

CBARC, Sherman Station, Moro

The experiment was established on a 28-acre site at the Columbia Basin Agricultural Research Center (CBARC) in Moro in the fall of 2003. The experiment has completed 4 crop-years so far (2004-2005 through 2007-2008). The soil is a Walla Walla silt loam (coarse, silty, mixed, mesic Typic Haploxeroll) and more than 4 ft deep. The Center receives an average of 11.5 inches of annual precipitation. Rainfall and soil at the station is representative of the average conditions in the target area.

Treatments

Crop rotations under evaluation are shown in Table 1. Each phase of each rotation appears every year. The treatments are replicated three times. There are 14 plots per replication and the minimum plot size is 48 ft by 350 ft, for a minimum total experimental area of 13.88 acres. Agronomic practices, such as planting date, planting rate, and fertilizer, herbicide, seed-treatment fungicide, and insecticide application, are based on the optimum management for each rotation and crop. Direct-seeding is conducted using the Fabro® drill.

Field operations

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

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

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

†CT = conventional tillage; DS = direct seeded.

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

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

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

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

Soil water measurements were taken throughout the growing season using a PR2® probe (Delta-T Devices Ltd. Cambridge, England). The probe senses the soil moisture content at 4-, 8-, 16-, 24-, and 40-inch depths by responding to dielectric properties of the soil at these depths. Readings were made on two access tubes in each plot. At each reading, two measurements were taken, each time with the probe rotated to a different direction.

Center of Sustainability

The experiment is located at the William Jepsen farm in Heppner, Oregon. In the past 4 years (2004-2005 to 2007-2008) cropping systems that are similar to the proposed cropping systems at the Sherman Station at Moro have been evaluated at this site (Table 3). The Center of Sustainability (COS) site receives, on average, similar crop year precipitation to Moro (11 inches), but it is shallower (2 ft deep) than the Moro site (over 4 ft deep). This makes it possible to determine the influence of soil depth on the alternate cropping systems. Data collection is the same as at Moro but the experiment is not replicated. However, the experiment has very large plots that measure 80 ft by 900 ft and it may be possible to split the plots and add at least one replication. In the meantime, data will be analyzed using valid statistical methods for unreplicated studies (Perrett and Higgins 2006).

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

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

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

Results and Discussion

CBARC, Sherman Station, Moro

Precipitation

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

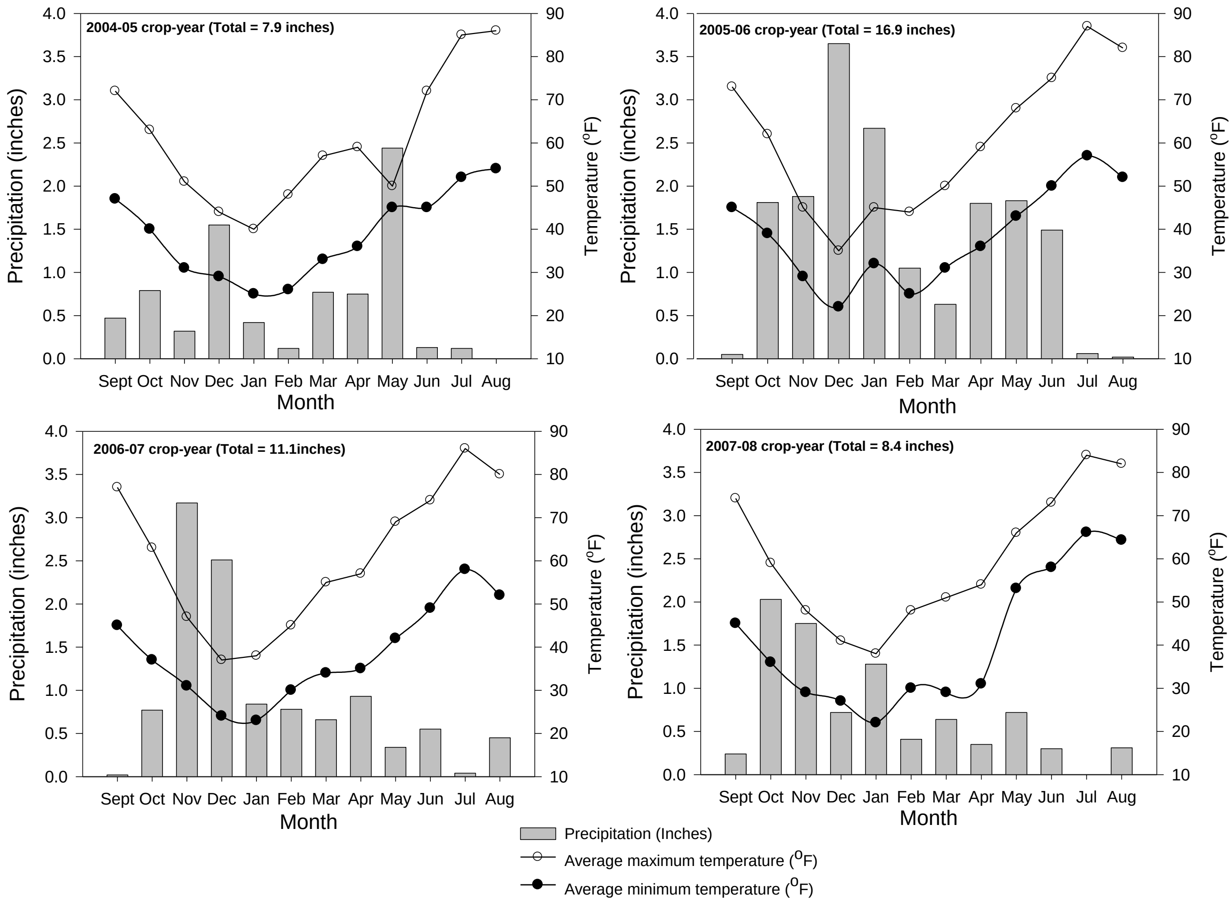

Figure 1. Precipitation and average maximum temperatures at the Columbia Basin Agricultural Research Center Sherman Station, Moro, Oregon, long-term cropping systems experiment from 2004-2005 to 2007-2008 crop years.

Soil water measurements

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

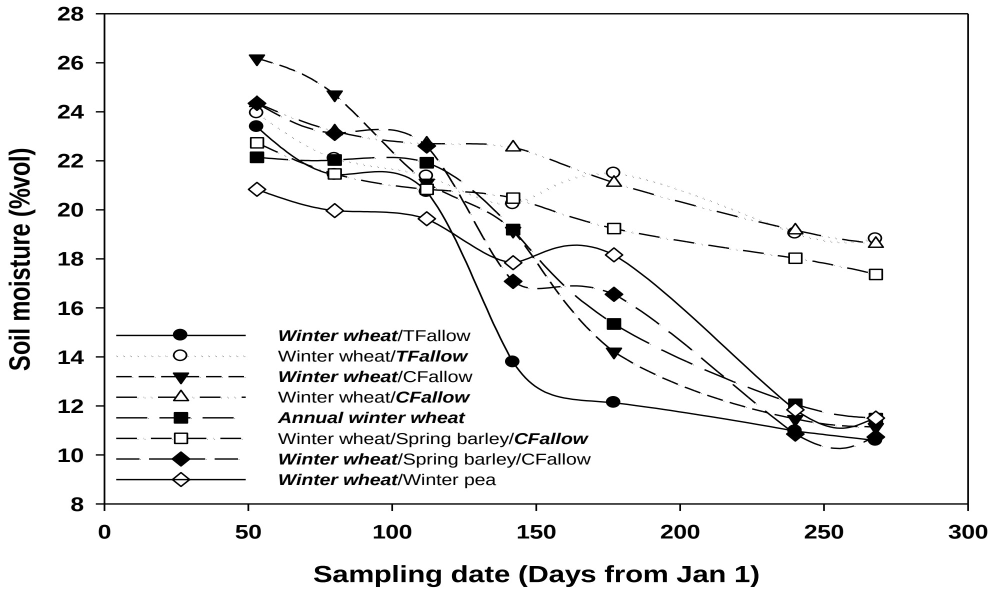

Figure 2. Average soil water content under all rotations in the 0- to 40-inch depth profile in 2008, at Columbia Basin Agricultural Research Center, Moro, Oregon. Data shown are for crop/treatment in boldface and italics of a rotation.

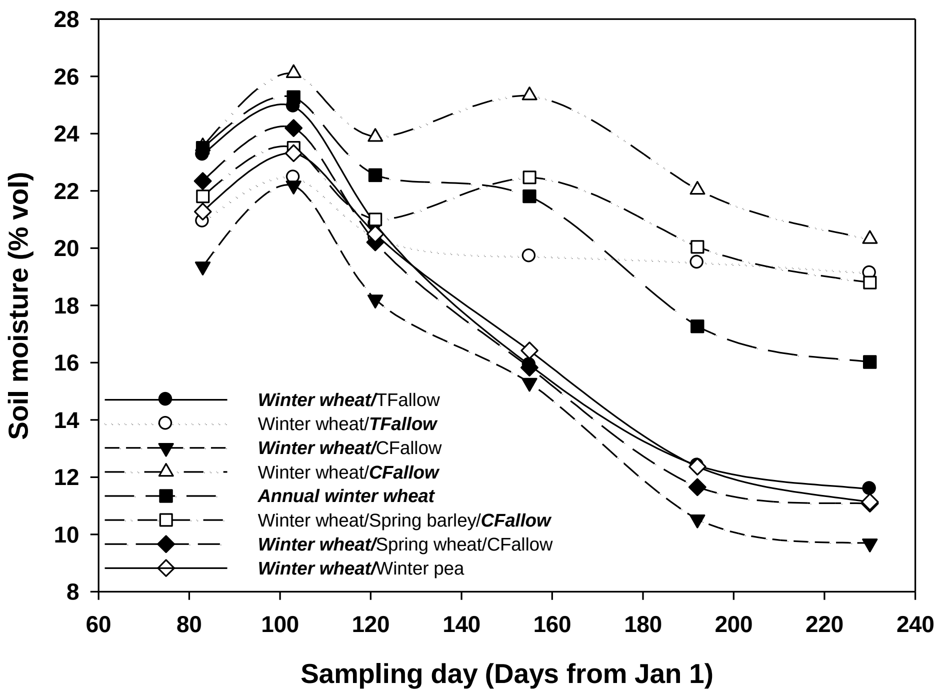

Figure 3. Average soil water content under all rotations in the 0- to 40-inch depth profile from March to August, 2006, at Columbia Basin Agricultural Research Center, Moro, Oregon. Data shown are for crop/treatment in boldface and italics of a rotation.

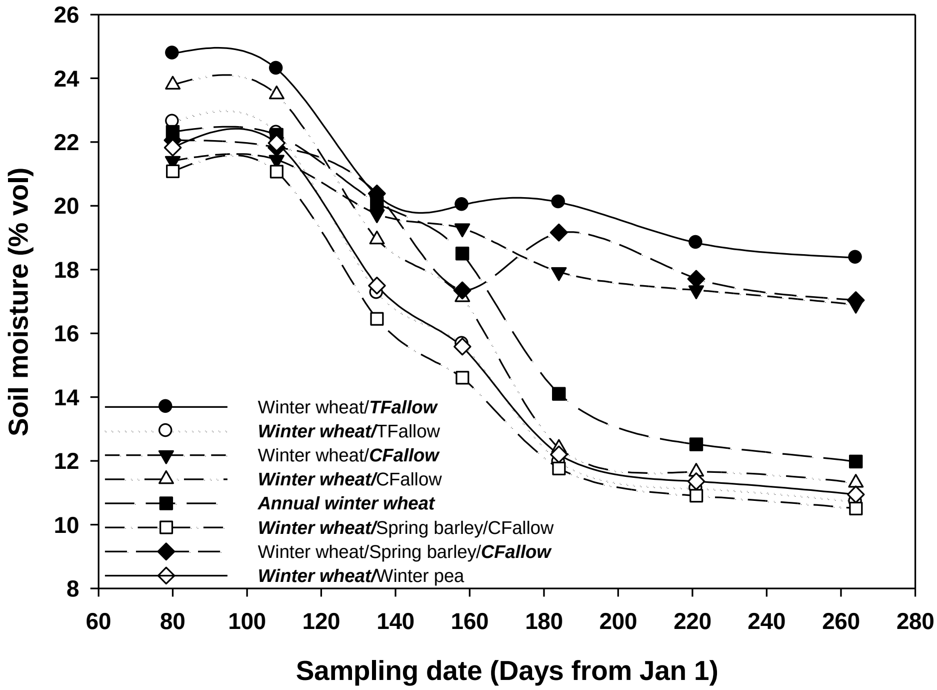

Figure 4. Average soil water content under all rotations in the 0- to 40-inch depth profile from March to September, 2007, at Columbia Basin Agricultural Research Center, Moro, Oregon. Data shown are for crop/treatment in boldface and italics of a rotation.

Weeds

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

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

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

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

Diseases

Fungal diseases of cereal crops

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

Fungal diseases of broadleaf crop

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

Root-lesion nematodes

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

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

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

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

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

[1]trt = treatment; WW = winter wheat, SW = spring wheat, SB = spring barley, WP = winter pea.

[2] SCI = lesions on sub-crown internodes, SR = seminal roots, CR = crown roots, RRR = Rhizoctonia root rot, TA = take-all, FCR = Fusarium crown rot, PRR = Pythium root rot, RLN = root-lesion nematode, "% plants" = percent plants exhibiting symptom described, "severity" = disease severity rating scale (0-4; 4 = most severe), lsd – least significant difference; ns = not significantly different.

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

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

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

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

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

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

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

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

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

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

** = significant at the 0.01 probability level

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

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

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

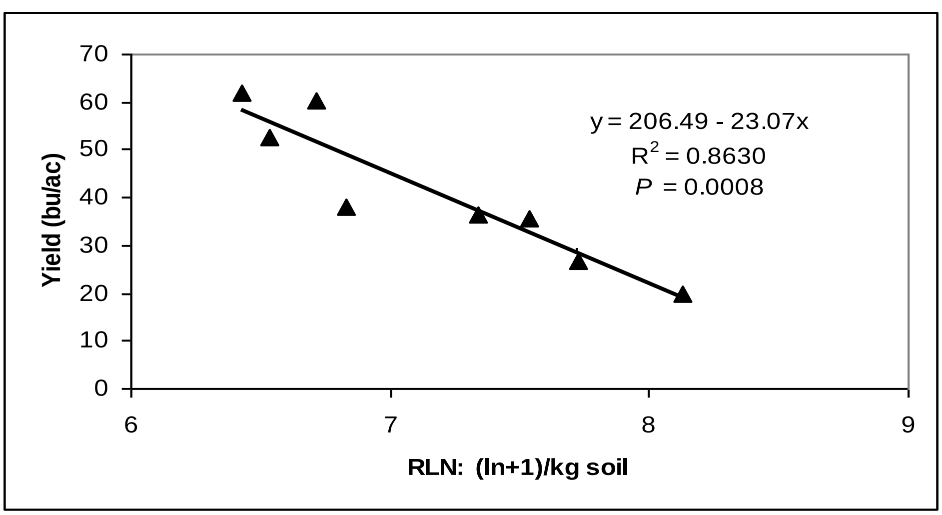

Figure 5. Relationship between root-lesion nematode populations (RLN; expressed as the log transformed number/kg of soil) and yields for winter wheat, spring wheat, and spring barley averaged over 3 years (crop years 2005-2007) as shown for the '5-yr average' in Table 8.

Grain yield of winter and spring crops under different cropping systems

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

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

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

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

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

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Grain yield

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

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

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

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

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