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AO5003

The Wilke Project – An Analysis of Alternative Crop Rotations in the Intermediate Rainfall Area of Eastern Washington

By
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Introduction

This publication presents the results of a 4-year project evaluating the feasibility of increasing crop diversity and intensity using direct seed or no-till techniques. In 1997, several growers from Lincoln County, WA, traveled to Pierre, SD, to observe the no-till or direct seeding research at the South Dakota State University Dakota Lakes Research Station. This work has changed farming practices in areas of South and North Dakota. Farmers there who were formerly using a wheat-fallow rotation have widely adopted annual cropping with diverse rotations using direct seeding practices. These growers returned believing that direct seeding had great potential to prevent soil erosion; improve air, soil, and water quality; add flexibility and diversity to their crop rotations; expand control options for weed, disease, and insect pests; and increase farm profit.

Eastern Washington is very different from the Northern Great Plains, particularly in temperature and precipitation timing; therefore, it is important to demonstrate successful adaptation of no-till cropping systems in this region. This group of growers proposed a public-private research project modeled after the Dakota Lakes Research Station in Pierre, SD. The main site chosen was the 350-acre Wilke farm located near Davenport deeded to Washington State University for research with satellite locations on grower farms. A number of cooperators and collaborators from both the public and private sectors developed cropping plans and provided land, labor or equipment, products, or financial support to complete the project.

The objectives of the project were: (a) demonstrate and extend adoption of diverse crop rotations in direct seed systems that promote natural resource stewardship through reduction of soil erosion by wind and water, (b) diversify crop rotations grown in the intermediate rainfall areas of the Pacific Northwest, and (c) implement integrated pest management practices under direct seeding conditions.

Materials and Methods

Project Design

Two crop rotations were initiated in the spring of 1998 at the WSU Wilke Research and Extension Farm near Davenport, WA, and on 5 cooperators' fields within a 30-mile radius of Davenport (near Mondovi, Deep Creek, Harrington, Sprague, and Wilbur). A sixth site at Egypt was discontinued after 1 year. Approximately 210 acres of the Wilke farm were placed into replicated strips or plots representing a 3- or 4-year rotation. The 3-year rotation was a modification of the traditional winter wheat/spring grain/fallow rotation commonly practiced in Lincoln County. This rotation was winter wheat/spring cereal/broadleaf. The 4-year rotation was modeled after a rotation found to be successful in the Northern Great Plains. This rotation is spring cereal/winter wheat/warm season grass/broadleaf. As mentioned above, the plots at the Wilke farm were replicated 3 times to allow statistical analysis of the data. Cooperator plots were not replicated, but multiple samples were collected in each field. Plot size ranged from 8 to 10 acres at the Wilke farm and 10 to 100+ acres on cooperator farms. With the exception of the Wilke farm in 1998, each part of the rotation was present each year in all locations. Each cooperator chose either a 3- or 4-year rotation to establish, while the Wilke farm had both rotations present. Within a rotation, cooperators were allowed to choose individual crops and varieties within a crop-type they believed would suit their farm operations, available moisture, and market opportunities. All field operations were performed using grower equipment. Data were also collected from 2 conventional tillage farms near the Wilke farm for comparison.

Sampling

Within a field or strip, 3 permanent sampling points were established where most sampling occurred over the 4 years of the project. Sampling methods are described below.

Weed populations. From the field sampling position, a 100-ft. transect was laid out at a 45° angle to the crop rows. A marker, 2 feet in length, was placed across the transect, 1 foot on either side. The number and species of each weed within this belt were tallied and recorded. Weed populations were evaluated once in the spring 4 weeks after planting and once prior to harvest.

Stand counts. A marker, 3 feet in length, was placed at 3 of the established random positions. The total number of crop plants on either side of the marker within the furrow were tallied and recorded for each field.

Insect populations. Insect monitoring occurred 4 weeks after planting and every 2 weeks during the growing season. At 5 predetermined random locations, 5 sweeps were taken at a 45° angle to the crop rows using an insect sweep net. All insects collected in the net were placed in plastic bags, labeled, placed in a cooler, and frozen for later identification.

Crop yield. All crops were harvested using commercially available equipment. Crop yield was determined from elevator and individual farmers' records.

Crop residue. Post harvest residue was evaluated in the fall at 3 locations in each field. A hoop, 42 inches in diameter (1 m^2), was placed on the ground over the residue. All residue within the hoop was clipped to ground level, with small pieces and old residue raked into a pile. The collected residue was placed into a 5-gallon bucket with a sieve screen on the bottom to sift out the unwanted soil. The residue was placed in a brown paper bag and weighed. Post harvest residue was evaluated immediately following harvest prior to fall seeding. If weather conditions were not favorable immediately following harvest, residue from late harvested crops was collected and evaluated in the spring prior to field operations.

Soils. Soil samples were collected and then analyzed by a commercial firm. Three locations were sampled within each field to create a field composite. Samples were collected to a depth of 6 feet using a subsoil probe. Samples from each foot were collected separately and labeled. Each sample was analyzed using the following parameters: nitrate, and moisture (1-6 ft.), sulfates (1-3 ft.), ammonium nitrate, phosphorus, pH, and organic matter (0-1 ft.). At the beginning and end of the 4-year rotation, pH and organic matter were measured in the top 1 foot, at 0-2”, 2-4”, and 4-12”, to determine any changes over the project period.

Water infiltration. Water infiltration was measured at previously established random locations within each of the fields. The method is a standard developed by the USDA (1999). The sampling area was cleared of surface residue to the soil surface. A 6-inch diameter hard plastic ring was driven into the ground to a depth of 3 inches. The soil was firmed around the inside edges of the ring to prevent seepage and minimize disturbance to the rest of the soil surface inside the ring. The soil surface inside the ring was lined with a sheet of plastic wrap to completely cover the soil and ring. The ring was filled with 444 ml (or 1”) of distilled water. The plastic wrap was removed gently by pulling it out, and leaving the water in the ring. The time required for the 1” of water to infiltrate into the soil until the surface glistened was recorded and later calculated into inches per hour it takes the soil to absorb the water.

Earthworms. Sampling methods used were national sampling protocols developed by Jill Clapperton for Worm Watch (Clapperton 1998). Modified hand sorting was used to determine the number and species diversity of earthworms. This method was used to study what species of earthworms were present in the soil.

In the spring, a location was chosen that occurred in a moist area, not on a dry hilltop. If there was a lot of surface residue it was sorted through to find any surface or litter dwelling earthworms. If any worms were found they were placed in a container, counted, and recorded on a data sheet. A shovel was used to dig and carefully scoop out the soil and place it on a plastic sheet to the side. The modified hand-sort method was used to gently break up the soil clumps and search for worms or cocoons and bag them for identification. Following identification all earthworms would be returned to the soil and soil surface residue returned back to place. Sampling was repeated at 6 locations in 11 different fields at the Wilke farm and 3 locations in each field at the Harrington farm.

Economics. A schedule of field operations performed for the year by each cooperator and at the Wilke farm operator were collected by team members. Based on farm prices and schedule of field operations, a set of enterprise budgets were engineered for each operation estimating costs and returns. This is a commonly accepted practice in the farm management profession.

Results

In this summary we are attempting to pool data from the 4 years of the project and do statistical analysis where possible. Because of the nature of the project, some statistical analysis is not acceptable. In these cases, averages and non-statistical data are presented and should be recognized as such. Because each cooperator only had 1 rotation on the farm, no comparisons among farms can be made, only within a farm. In some cases, data from cooperator farms are pooled together. Where statistical inferences are made, fields, years, or multiple sampling data were used as replications. The project began with 6 farmer cooperators, but only 3 of these cooperators completed the whole 4-year project.

Climatic Conditions

Precipitation was above the long-term average at both Davenport and Harrington in 1998 and 2000 and below average in 1999 and 2001 (Table 1). Because crop production in the Pacific Northwest relies heavily on stored soil moisture, dry fall and spring precipitation for the last 2 years of the study limited crop yield and profitability in 2000 and 2001. For example, during the soil recharge months, October through April, Davenport received 70% and Harrington received 59% of the historic precipitation for the 2001 growing season. The effects of this reduced precipitation will be discussed below.

Table 1. Total monthly precipitation for Davenport (Dav) and Harrington (Har) for study period.

	1998		1999		2000		2001		Long-term average	
Month	Dav	Har	Dav	Har	Dav	Har	Dav	Har	Dav	Har
	inches									
Jan.	2.94	2.11	1.23	1.14	1.71	1.65	0.63	0.61	1.78	1.40
Feb.	1.53	1.70	2.03	2.10	1.52	1.40	0.41	0.36	1.29	1.10
Mar.	1.14	0.86	0.19	.025	2.39	2.00	1.37	1.34	1.42	1.16
Apr.	0.46	0.43	0.20	0.45	1.72	1.61	0.98	1.10	1.06	1.00
May	2.71	2.06	0.86	0.58	1.63	1.23	0.95	0.58	1.34	1.16
Jun.	0.81	0.68	1.23	1.54	1.40	1.39	1.21	0.79	1.03	0.90
Jul.	0.92	0.64	0.41	0.20	0.32	0.11	0.10	0.23	0.66	0.56
Aug.	0.33	0.13	0.49	0.61	0	0	0.28	0.33	0.56	0.46
Sept.	0.12	0.63	0.05	0	0.95	1.17	0.13	0.15	0.68	0.57
Oct.	0.29	0.21	0.55	0.70	0.99	0.77	1.35	1.41	1.03	0.89
Nov.	2.54	2.57	1.79	1.88	2.13	1.05	2.23	2.32	1.93	1.70
Dec.	3.04	2.92	1.57	1.81	0.93	0.88	1.83	1.74	2.08	1.89
Total	**16.83**	**14.94**	**10.6**	**11.26**	**15.69**	**13.26**	**11.47**	**10.96**	**14.86**	**12.78**

Weed Population Changes

Weed management is a major concern in transition to direct seeding and one of the most costly operations to consider. One of the theories behind intensive cropping is, with a mixture of winter and spring crops, certain weed species are selected against and should be less of a problem. For example, winter annual grasses such as jointed goatgrass or downy brome (cheat grass) should be less of a problem in a spring cropping system. Likewise, wild oats should be less of an issue during winter cropping. Also, adding warm season crops that can be planted later should aid in management of early germinating weeds and multiple weed flushes. In this project, we observed a portion of this theory with some weed populations decreasing in number while direct seeding or management has favored other species.

On the Wilke farm, when comparing the 3- and 4-year rotations, wild oats were the only weed species that showed a significant difference between the 2 rotations. Averaged over years, wild oat populations were on average 8.9 and 0.25 plants/yd^2 in the 3- and 4-year rotations, respectively. In the 4-year rotation, 2 years out of a spring cereal reduced wild oat populations (Table 2.) cereals are grown, wild oat populations can be reduced. Averaged over rotations, prickly lettuce, knotweed, and wild oat populations decreased over time, while cone catchfly and downy brome populations increased (Table 2). Weeds, in particular wild oats, contributed to lower than expected yields for many crops and was one of the most expensive crop inputs. The method of recording weed populations when dealing with a "resident" population may not accurately describe these populations because of the special variability of weeds in a field. Some sampling points or field areas had high weed populations while others had very few weeds. One such case is Russian thistle in the plot area, but not in the area sampled.

Within a rotation, weed populations varied by crop (Table 3). In the 3-year rotation, wild oat population was greater in spring cereal than in winter wheat or the broadleaf crop while downy brome populations were greater in winter wheat crops. In general, broadleaf weed populations deceased in both rotations except for Canada thistle (Figures 1 and 2). Wild oat populations decreased in both rotations while downy brome populations increased in the 3-year rotation (Figure 3).

Cooperator fields also had changes in weed populations. Downy brome populations generally decreased, but populations of kochia, prickly lettuce, and Russian thistle increased in some cases. Other shifts in weed populations based on observations are a reduction in field bindweed (morning glory), which does well in tilled systems. Based on ours and other grower observations, other perennial weeds such as Canada thistle, dalmation toadflax, and mullein have increased in area. (Data not shown.)

Weed management is also critical in crop selection. Growing a crop with limited weed control options needs to be considered. If weeds are allowed to grow and not controlled because there are no registered herbicides, not only can yield be reduced because of competition, but it can be the cause of future weed problems. (See the section at the end of the agronomic results that describe some of the observations not shown in the data.)

1. Weed management was one of the most costly operations in transitioning to direct seeding.
2. Annual broadleaf weed populations generally decreased over time in both 3- and 4-year crop rotations.
3. Canada thistle populations increased during the study and increases were greater in the 4-year rotation.
4. Wild oat populations decreased in both rotations, but the decrease was less in the 4-year rotation due to poor control in proso millet.
5. Downy brome decreased in the 4-year rotation, but increased in the 3-year rotation due to the

shortness of rotation to deplete the seedbed and poor completive ability of winter wheat in a re-crop situation.

6. Total crop yield was greater in the 3-year rotation compared with the 4-year because of the poor yield of proso millet in the rotation.
7. More research is needed to identify more profitable crop rotations and address weed and other management practices in a direct seed system.

Table 2. Change in cone catchfly, prickly lettuce, Shepherd's purse, knotweed, wild oat, and downy brome populations over time in direct seeded rotations at the WSU Wilke farm[†].

Year	Cone catchfly	Prickly lettuce	Shepherd's purse	Knot-weed	Wild oat	Downy brome
	--------------------------------	plants/yard^2	----------------------------------			
1999	0.6 c	9.2 a	0.8 b	2.0 a	136.9 a	0.8 b
2000	8.4 b	3.0 b	4.8 a	0.4 b	41.0 b	9.0 a
2001	20.9 a	0.9 c	0.7 c	0.1 b	13.0 b	11.7 a
LSD (0.05)	4.0	3.5	3.5	0.5	16.0	7.8

[†] Means within columns followed by the same letter are not significantly different according to test at the 5% level of probability.

Table 3. Wild oat, downy brome, and prickly lettuce populations in Wilke 3- and 4-year crop rotations, averaged over years[†].

Rotation and Crop	Weed species		
	Wild oat	Downy brome	Prickly lettuce
	---------------------------	plants/yard^2	--------------------------
3-year			
W. wheat	1.7 b	4.2 a	0.01 ab
Sp. cereal	4.3 a	0.1 b	0 b
Broadleaf	1.9 b	0.1 b	0.03 a
4-year			
W. wheat	2.8 b	0.5 a	0.08 b
Sp. cereal	2.7 b	0 b	0.1 ab
WS grass	6.4 a	0.1 ab	0.1 ab
Broadleaf	2.5 b	0.3 a	0.2 a

[†]Means within a rotation and species followed by the same letter are not significantly different at the 5% level of probability using LSD procedure.

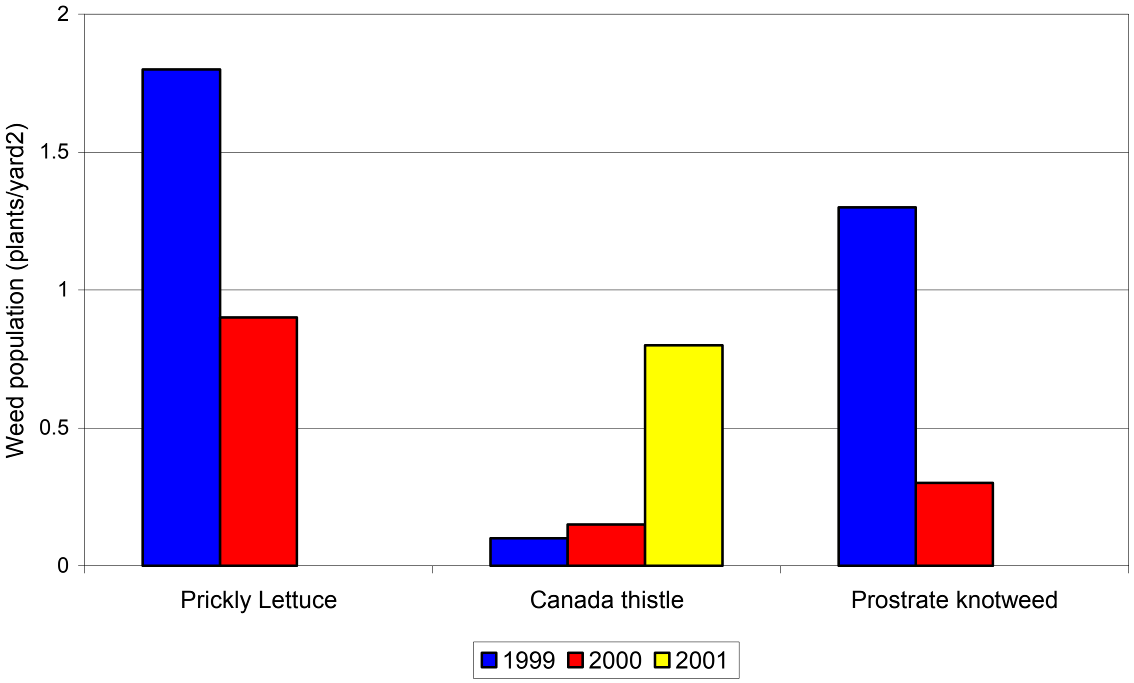

Figure 1. Change in broadleaf weed populations over years in Wilke 3-year crop rotation. Means with the same letter within a species are not significantly different using LSD procedure (p=0.05).

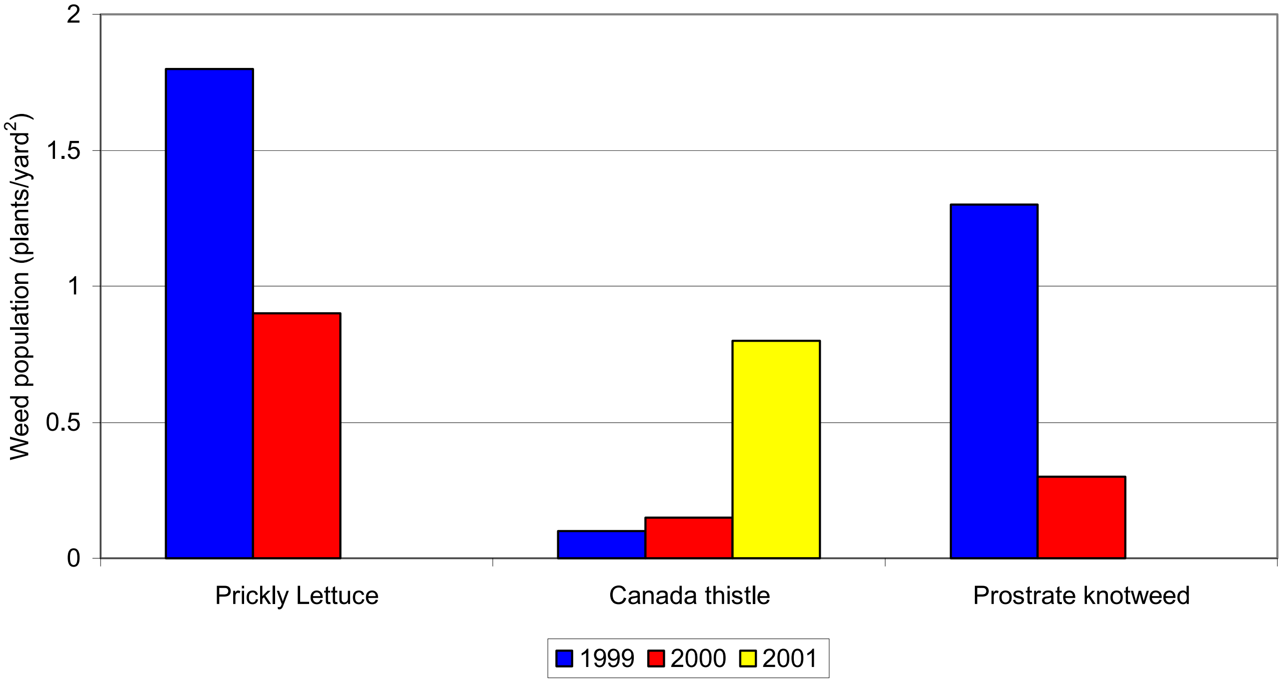

Figure 2. Change in broadleaf weed populations over years in Wilke 4-year crop rotation. Means with the same letter within a species are not significantly different using LSD procedure (p=0.05).

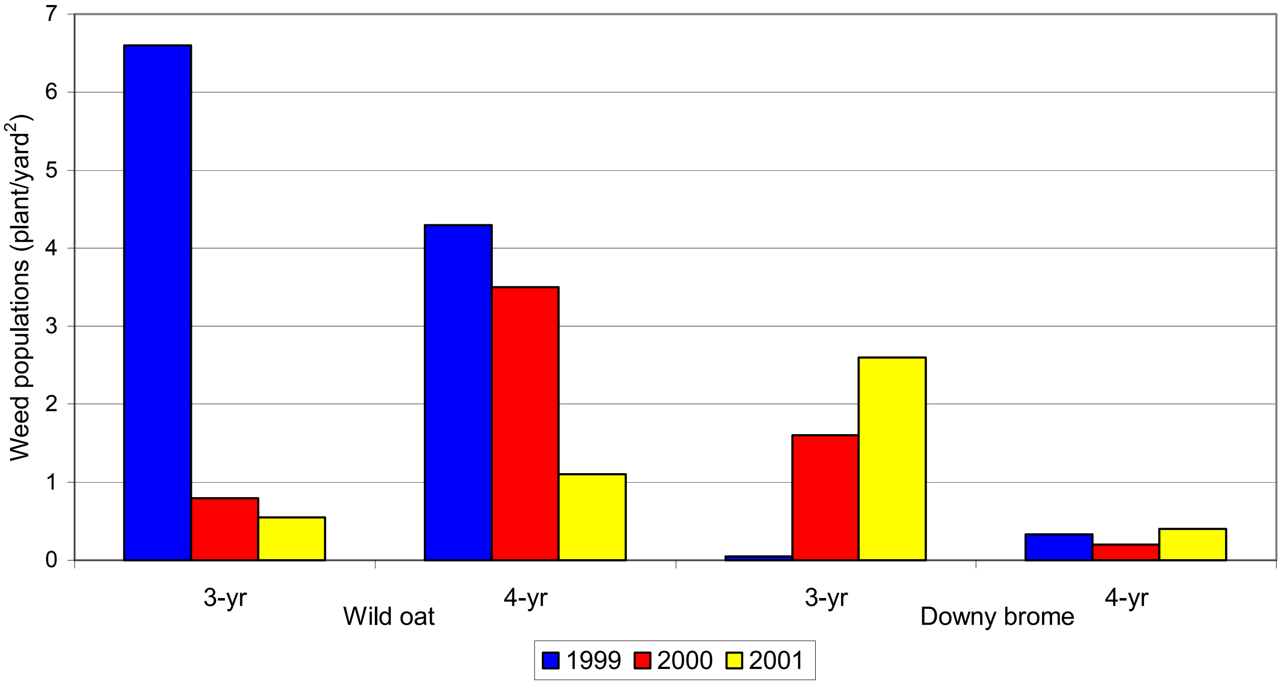

Figure 3. Change in wild oat and downy brome populations over years in Wilke 3- and 4-year rotations. Means followed by the same letter within a rotation and species are not significantly different using LSD procedure (p=0.05)

Insects

We collected both pest (aphids, leafhoppers, thrips) and beneficial insects (lady beetles, parasitic wasps, damsel bugs, soft winged flower beetles). The following comments are based on our observations.

Insect populations varied from year to year of the study period, but have shown a general trend of pest insects peaking in early July and outnumbering beneficial predators that increased soon afterwards (Figure 4).

Small grain fields that had been in canola the previous year demonstrated higher aphid populations than did fields of small grains following small grains. This was noted in 2 out of the 4 years of the study, at 2 different cooperator farms, suggesting a carryover in populations (data not shown).

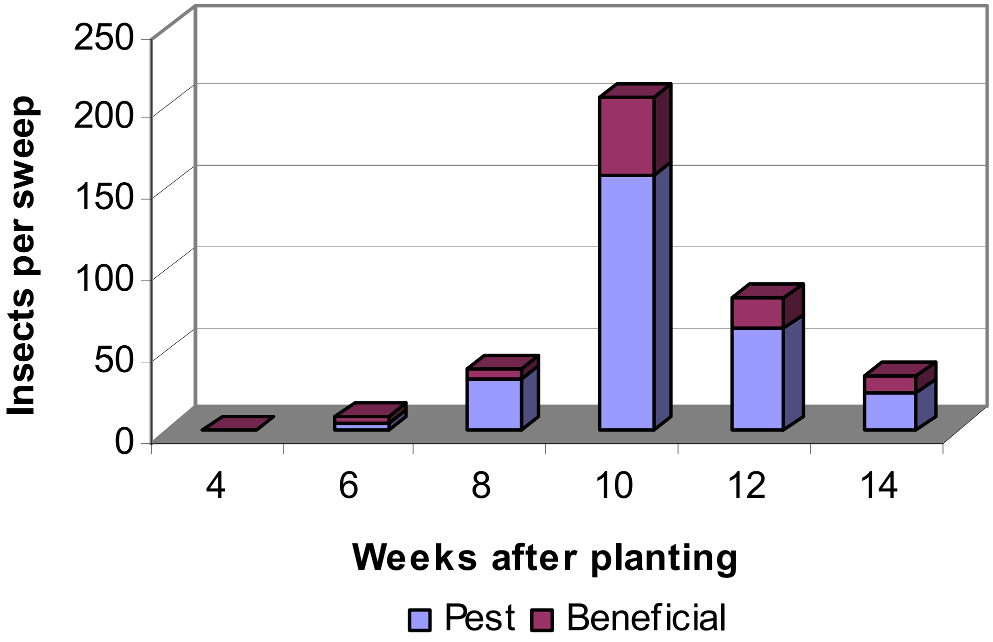

Figure 4. Insect population change during cropping season, averaged over years and crops.

Crop Disease

The only incidence of disease we observed was take-all in 2000 in a winter wheat field following safflower planted in 1998. Otherwise, fields have been disease free.

Crop Yield and Residue

Crop yield is generally reported as pounds of crops produced per acre (lb/a) in order to average and add together cereals and broadleaf crops for comparison of yields between rotations. Crop yield varied from year to year averaged over rotations and crops. In most cases, crop yield was greatest in 2000, while lowest average yield was in 2001, due to dry growing conditions (Table 2). Averaged over rotations and crops, crop yield ranged from 1441 to 1638 lbs/a at the Wilke farm. Cooperator crop yield ranged from 1115 to 2544 lbs/a during the study period (Table 5). During the same period, the conventional cooperator yield was 2311 lbs/a, averaged over years, crops, and fallow. On the Wilke farm, the 3-year rotation produced 22% more crop than the 4-year rotation, averaged over crops (Table 3). This is mainly due to the poor performance of the warm season grass (proso millet) in the 4-year rotation (Table 4).

At the Wilke farm beginning in 2000, winter wheat replaced spring wheat following the broadleaf crop in the 3-year rotation. In the 4-year rotation, winter wheat was planted as the second small grain in the rotation sequence. During the last 2 years of the study, winter wheat out-produced spring wheat by an average of 18 bu/a (data not shown). During this period, winter wheat yield ranged from 2580 to 3660 lbs/a (43 to 61 bu/a) while spring wheat yielded from 1800 to 3060 lbs/a (30 to 51 bu/a). In the 3-year rotation, barley followed wheat in the rotation and averaged 2489 lbs/a (1.25 T/a) and ranged from 1500 to 3000 lbs/a (0.75 T/a to 1.5 T/a) (Tables 4 and 5).

Alternative crops grown in the project included yellow mustard, canola, safflower, sunflowers, peas, buckwheat, flax for broadleaf crops, and proso millet and corn for warm season grasses (see Tables A1 through A5 for specific crops and varieties). One cooperator grew corn and sudangrass that was harvested for forage. These crops were grown with varying degrees of success. Several of the alternative crops were sensitive to frost, heat, and generally not well adapted to the climate. For example, sunflowers or corn may require too long a growing season or require more summer rainfall than is customary in the area. More work is required to select crops and varieties that may be suitable for the climate. Cool season broadleaf crops may be better suited to the area.

Crop residue ranged from 5400 to 7635 lbs/a during the study period (Table 2). On the Wilke farm, the greatest amount of residue was produced during the year with the lowest yields. While the 3-year rotation produced greatest yields overall, the 4-year rotation produced slightly greater residue levels (Table 3). This is likely due to inclusion of proso millet in the rotation that produced residue amounts nearly equal to small grains and may decay at a slower rate. Overall, residue levels did not increase over the study period indicating residue is breaking down at a rate nearly equal to what is being produced. Cooperator residue levels varied by location (Table 5).

Because of the poor yield of the warm season grass, it has been eliminated from the 4-year rotation on the Wilke farm and replaced with barley in an attempt to make the rotation more profitable. We are also attempting to make the rotations more rigid, planting the same broadleaf crop and wheat varieties in both rotations to allow streamlining of operations and more accurate analysis of the data.

Table 3. Average crop yield and residue levels for the Wilke farm from 1998 to 2001 averaged over rotations and crops[†].

Year	Yield	Residue
	lb/a	lb/a
1998	1638 a	5400 b
1999	1569 b	5401 b
2000	2069 b	5186 b
2001	1441 c	7635 a
LSD (0.05)	84	663

[†] Means within columns followed by the same letter are not significantly different according to test at the 5% level of probability.

Table 4. Wilke farm crop yield and residue averaged over crops and years[†].

Rotation	Yield	Crop Residue
	lb/a	lb/a
3-year	1926 a	5787 b
4-year	1507 b	5902 a

[†] Means within columns followed by the same letter are not significantly different according to test at the 5% level of probability.

Table 5. Crop type yield in Wilke 3- and 4-year rotations averaged over years[†].

	Yield[b]		Crop residue	
Crop type	3-year	4-year	3-year	4-year
	--------lb/a--------		--------lb/a--------	
Sm. grain 1[‡]	2567 a	2143 a	6394 a	5942
Sm. grain 2	2489 a	2656 a	6150 a	6319
Warm season grass	NA	403 c	--	5816
Broadleaf	663 b	824 b	4760 b	5510
LSD (0.05)	174	134	1195	NS

[†]Means within columns followed by the same letter are not significantly different according to LSD procedure at the 5% level of probability.

[‡]Crop type within a rotation - 3-year: Sm. grain, 1 (winter or spring cereal); Sm. grain 2 (spring cereal); 4-year: Sm. grain 1, (spring cereal); Sm. grain 2, (winter or spring cereal).

Table 6. Wilke project cooperator yields and crop residues averaged over years[†].

Cooperator (rotation)	Crop Type	Yield	Crop Residue
		lb/a	lb/a
3-1 (3-yr)	Sm. grain[‡]	2977 a	8677
	Sm. grain	2812 a	5858
	Broadleaf	455 b	5225
	LSD	1769	NS
3-2 (3-yr)	Sm. grain	1977 b	4303
	Broadleaf	759 c	4516
	Sm. grain	2370 a	5489
	LSD	121	NS
4-1 (4-yr)	Sm. grain	3048 a	5588
	Sm. grain	3535 a	5669
	Warm season grass	875 b	4910
	Broadleaf	906 b	7413
	LSD	1010	NS
4-2 (4-yr)	Sm. grain	2183 a	7244
	Sm. grain	2018 a	7481
	Warm season grass	620 b	6580
	Broadleaf	865 b	6412
	LSD	610	NS

[†] Means within columns and sites followed by the same letter are not significantly different according to LSD procedure at the 5% level of probability.

[‡] Crop type within a rotation: 3-year Sm. grain 1 (winter or spring cereal), Sm. grain 2 (spring cereal): 4-year Sm. grain 1 (spring cereal), Sm. grain 2 (winter or spring cereal).

Soil Quality

Organic matter. Organic matter is a key component in improving soil physical properties. It contributes to increased water holding capacity, increases available plant nutrients, and holds soil particles together. Crop rotation and incorporation of crop residue are important for maintaining organic matter (Kennedy 1999). Increased organic matter should reduce wind and water erosion by holding the soils together. This will make soil less available to be blown away by wind, and water to be captured in the soil, rather than running off soils.

In 1998, we measured baseline soil organic matter at 0 to 2”, 2 to 4”, and 4 to 12” depths. In the spring of 2002, these measurements were repeated in approximately the same locations in each field. There was a trend for increased soil organic matter (carbon) in the top 1 foot of soil, especially in the to 0-2" range (Tables 6 and 7). The only statistical difference in organic matter was at the 0–2" range on the Wilke farm although in some cases, cooperator organic matter increased by as much as 1%. This is likely due to the small number of samples collected and analyzed. Greater depths also showed a trend for increase, but these were more moderate. The conventional cooperators' fields also showed a trend for increased organic matter likely due to adopted conservation practices.

Table 7. Soil pH and organic carbon in 1998 and 2002 in the top foot of soil after 4 years of direct seeding on the Wilke farm, averaged over 3- and 4-year rotations[†].

Soil depth	Organic carbon 1998	Organic carbon 2002	pH 1998	pH 2002
(in)	------(%)-------			
0-2	3.1	3.9*	6.0	6.1
2-4	2.8	2.9	5.7	5.7
4-12	2.1	2.1	6.3	6.1

[†] Pairs within a depth range followed by an asterisk(*) are significantly different at the 5% level of probability.

Table 8. Comparison of Wilke cooperator soil organic matter content and pH measured at 0-2, 2-4, and 4-12 inches in 1998 and in 2002 averaged across fields[†].

Cooperator	year	Organic matter 0-2	Organic matter 2-4	Organic matter 4-12	pH 0-2	pH 2-4	pH 4-12
		(depth in inches)					
		-------%-------					
Conv. 1	1998	2.6	2.5	1.9	6.1	5.8	6.2
	2002	2.9	2.7	2.2	6.3	5.9	5.9
Conv. 2	1998	3.1	2.5	1.9	5.7	5.4	6.0
	2002	3.8	3.1	2.3	6.2	5.3	5.9
3-year	1998	3.3	3.1	2.1	6.1	5.7	6.4
	2002	4.3	3.3	2.3	6.2	5.4	6.0
4-year 1	1998	3.7	3.2	2.4	6.1	5.7	6.6
	2002	4.4	3.8	2.7	6.5	5.9	6.4
4-year 2	1998	3.0	2.3	1.9	5.4	5.3	6.0
	2002	3.9	2.3	1.7	6.2	5.5	6.1

[†] Means for years within a depth range were not significantly different at the 0.05% probability level.

Soil pH. Acidification of direct seeded soils has been a concern in the higher rainfall areas of the Palouse. Data collected in 1998 and again in 2002 indicate that soil pH is not decreasing under direct seeded systems (Tables 6 and 7).

Nitrate movement. Baseline information for nitrate levels was obtained in 1998 to monitor the movement of nitrogen fertilizer in the soil in a more intensively cropped system. Results indicate that there was a slight increase in nitrate levels in the 3- and 4-foot levels in 2002 compared with 1998 (Figure 5). This indicates that care needs to be taken to ensure that nitrate movement is minimized in the profile. There was no statistical difference between nitrate levels in the soil profile, although there is a trend for less nitrate in the 5th and 6th foot of the 4-year compared with the 3-year rotation, possibly due to growing deep-rooted crops like sunflowers in the rotation (Figure 6). Cooperator fields did not show a significant increase in nitrate levels in the soil profile. In fact, 2 farms showed a decrease in nitrate levels over all (data not shown).

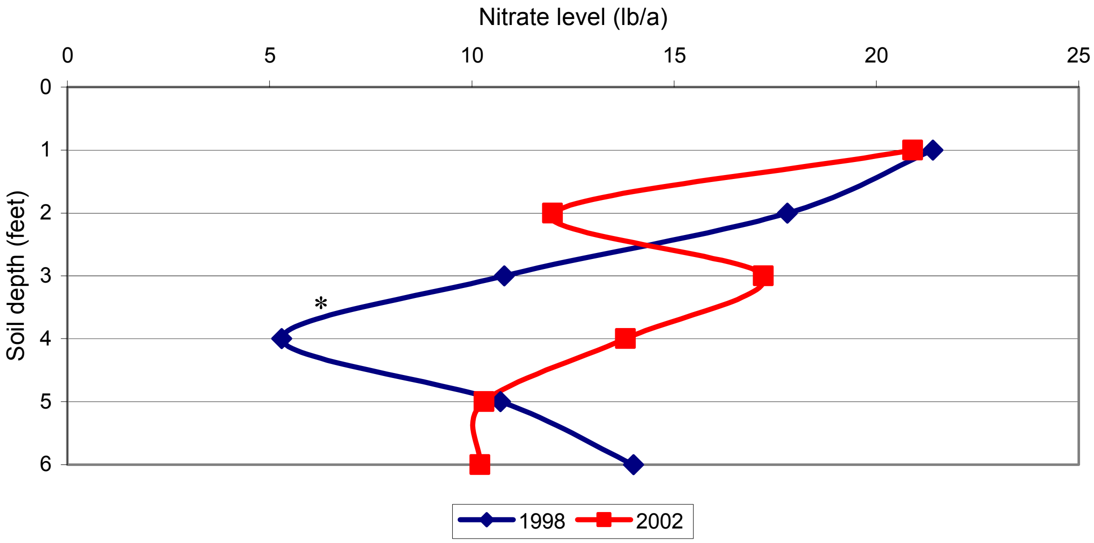

Figure 5. Soil nitrate levels in 1998 and 2002 for direct seeded fields on the Wilke farm. * indicates significant difference within depth level (p=0.05).

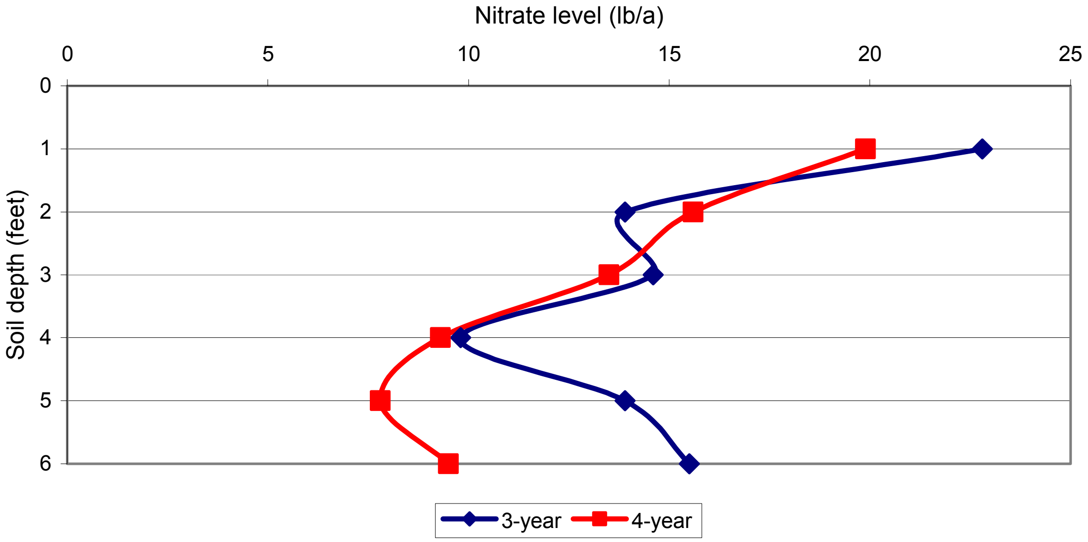

Figure 6 . Soil nitrate levels comparing 3- and 4-year crop rotations on the Wilke farm averaged over years.

Water infiltration. Water infiltration is the rate at which water enters the soil and depends on soil type, soil structure, or amount of aggregation, and water content (USDA 1999). Tillage affects water infiltration rate by temporarily loosening the soil, causing rapid water infiltration. However, tillage also disrupts aggregation and soil structure, creating compaction. Soils that are not disturbed will enhance water infiltration because of larger pore size and soil aggregation. Root and earthworm channels can create continuous pores into the profile. Compacted or disrupted soils have less pore space resulting in lower infiltration rates. The infiltration rates in inches per hour that have historically been used in soil survey classes are as follows: 0.6 to 2 inches/hour (moderate), 2 to 6 inches/hour (moderately rapid), and 6 to 20 inches/hour (rapid).

Average infiltration rates increased from 2.8 to 10.0 inches per hour comparing data from 2000 with the 2001 data. Infiltration rates ranged from 1.1 to 6.3 in 2000 to 3.6 to 20.2 inches per hour in 2001. Infiltration rates in the cooperator fields have also increased from 3.0 to 4.8 to 3.2 to 11.4 inches per hour, depending on location, in 2000 and 2001, respectively. This dramatic increase helps avoid runoff from rainfall and rapid snowmelt.

Erosion. We observed slight water erosion at the Wilke farm in the spring of 2000 after several rains on frozen soil. In the spring of 2002, there was some soil movement in a waterway, but it would have been much worse if the soil was left bare.

Earthworms. Earthworms can be very beneficial in direct seed systems. In direct seeded fields they become the primary source of nutrient cycling by ingesting and recycling soil organic matter. As the surface residue increases and soil disturbance decreases, it creates a habitat suitable for earthworm growth. We have sampled intensively for earthworms both on the Wilke farm and at one of the cooperators' farms. As yet, no earthworms have been found, although worms were found at the old home site at the Wilke farm. Earthworm populations will need to be monitored over time.

General Observations

Following are some of the empirical observations from researchers and cooperators.

Weeds

- Weeds are one of the major problems in direct seeding.
- Growers are seeing shifts in weed species with new cropping systems.
- Wild oat populations tend to increase with spring cropping and will continue to germinate with moisture; up to six flushes were seen in 2000.
- On the Wilke farm, growing safflower for 1 year without being able to apply any herbicides greatly increased the wild oat problem on the farm.
- Spring wheat is also a weak link in wild oat control.
- Field bindweed tends to decrease with direct seeding. One grower who had a substantial infestation on some new ground now has to search for bindweed plants after 3 seasons of direct seeding.
- Dalmatian toadflax and mullein are both very susceptible to tillage and are increasing with direct seeding.
- Canada thistle seems to be increasing both in conventional tillage and with direct seeding; it does well in low disturbance systems.
- We also need a good tool for Russian thistle management.
- In 2000, an early frost the first week of September stunted Russian thistle plants and eliminated their usual post harvest flush.
- Keep in mind crop rotational restrictions, i.e., don't get caught with long plant-back restrictions.

Soil Fertility

- Soil fertility is still a key issue – precision, timing, and amount.
- One cooperator, who had not direct seeded as long, applied 40-50 lbs N in the fall of 1999. He was encouraged to see it evenly distributed in the top 2-3 feet in the spring of 2000.
- A third cooperator used all Solution 32 in the spring of 2000, and his malt barley was too high in protein.

Crops

- Rotation, diversity, and crop selection continue to be an issue.
- A warm season grass is probably not a viable option in this area.
- With consistent direct seeding, one grower cooperator has noticed that crops can germinate quicker and from greater depths than normally recommended for that seed size.
- Seed can emerge quite easily through the duff layer, so small seeds can still emerge when placed deeper to make good contact with soil and moisture. Things to be aware of: (1) For example, if you are planning to apply glyphosate post-seeding and prior to crop

emergence, you may have a shorter spray window than anticipated. (2) Frost-sensitive crops that germinate quicker than normal may need to be seeded later so that the danger of frost is less as they emerge.

- If you are choosing a crop variety to obtain a premium in a niche market, especially an alternative crop with limited yield data from our area, be sure you know its yield potential. In 1998, red proso millet had a higher price than white proso millet on the birdseed market. It may have been possible to harvest it direct without swathing. However, the yield potential was lower than for the white millet so the price premium was not advantageous.
- Weather affects crops. This statement is too obvious. However, it underscores the value we have obtained from a hundred years of breeding cereals (wheat and barley) that are well adapted and stable in our Pacific Northwest environment. Alternative crops that have not benefited from this research investment are far more susceptible to weather fluctuations. Unseasonably hot weather in 1998 and drought in 2000 reduced yields of most of the alternative crops. Mustard at the Wilke farm was affected more than an early maturing canola variety grown 3 miles away, even though mustard is supposedly less heat sensitive than canola. In 1999, frost after emergence damaged mustard and canola stands. Seedlings emerging through heavy residue were actually more susceptible to frost than in areas where the ground was clear of residue and heated more quickly.
- If a crop has a rotational benefit in the system, don't cancel this out with other management decisions (e.g., losing patience). One of the Wilke crop rotations includes a warm season grass to allow a wider window in the spring for managing weeds prior to seeding. In 1998, we seeded millet on June 6, which allowed for 3 glyphosate applications beforehand and greatly reduced wild oat populations. In 1999, we followed a recommendation from the Midwest and seeded the millet earlier (May 24). The spring was unusually cool, and although there were 2 glyphosate applications, a lot of wild oats germinated after seeding. Consequently, we missed a major rotational benefit of this crop.
- Watch nature (soil temperature and moisture) more than traditional dates to determine optimum seeding time. In 1999, the Wilke farm was sprayed with Roundup™ prior to seeding in mid-April. However, with a cold, dry spring, very few weeds emerged. A second, post-seeding pre-emergence glyphosate application was necessary, as there was a sudden flush of weeds.
- Make sure that a new alternative crop has pesticides registered for weeds and other potential problems. Safflower in 1998 had one of the better returns of alternative crops on the Wilke farm. However, lack of registered herbicides for grassy weed control makes it a risky rotational crop.
- Pick rotational crops based on potential for marketability, pest and weed management, and rotational benefits.

<u>Miscellaneous</u>

- Chaff spreaders on combines are a must. Chaff spreading reduces problems with seed germination and nutrient tie-up that may be associated with chaff rows.
- Getting good seed to soil contact is crucial to obtaining a good stand. It requires extra time to achieve this.
- Seeding depth control and fertilizer placement are important criteria in drill choice.

An Economic Analysis of the 3- and 4-Year Crop Rotations of the Wilke Project

Introduction – Policy and Economic Context. The economics of the 3- and 4-year rotations were analyzed. Explanations about the makeup of those rotations are found in the body of this report. The analysis strove to develop information useful to area producers as they made comparisons with the Wilke project results and their own practices. Additionally, the management of the financial risks in agriculture is a major challenge for all producers. Conclusions are drawn about the risks introduced by these cropping rotations.

The project began 3 years after the 1996 farm bill which was popularly called "Freedom to Farm." The 1996 bill released farmers from many of the acreage restrictions present in earlier farm bills, hence the "freedom" to farm name. Non-cereal grain crops could be grown on wheat and barley acreage without penalty from the government program. The freedom of cropping choices in "Freedom to Farm" turned loose a desire among many producers to explore alternative crops and production systems. The intent of "Freedom to Farm" also implied that producers would need to bear more of the financial risks associated with their farming operations.

The 4 years of the project were years in which prices for the commodities grown were at historical lows 3 of the 4 years and in the 4th year, prices were low, although not historically low. Wheat prices remained at or below the government loan rates for much of the marketing years of 1998–2000. As a reference, the loan rates set as part of the 1996 Farm Bill were considered to be so low that prices could not conceivably fall to those levels during the 7-year life of the farm bill. Another anomaly was that the prices of almost all commodities were low during the same time frame. One economic reason for bringing non-cereal grains into the rotation is for risk management. That is, the assumption being that if one crop's prices are low, there is a reasonable chance others will be profitable, therefore spreading the financial price risk across several commodities. Since prices of all commodities were low during this 4-year period, there were no price risk management benefits from the non-cereal grain crops.

Markets were not well developed for all of the crops grown during the project. Well-developed markets are available for wheat, barley, corn, peas, and the oil seed crops, canola, mustard, and flax. For the other crops, finding markets was often problematic. Marketing challenges for the other crops included having only one buyer without well-established quality standards. The price quoted was often not the price received as quality issues downgraded the prices. An additional cost/risk was the need to spend significant time finding the niche markets, processing the crop into a form acceptable by those markets, or not being able to find a market at all. Our analysis does not reflect these costs.

The paradox is that well-developed markets and marketing channels usually mean highly competitive "commodity" markets, often where prices are driven by global competition. In competitive markets, being a low-cost producer is a key to profitability. Developed marketing channels for oilseeds often means securing a contract for that production and the opportunities for contracts are limited to 2 or 3 firms. Niche markets hold the possibility of higher prices, but bring additional risks and costs first to find the niche and then develop the required relationships. Unless the producer can develop a retail market directly, the production is still sold to a middle person, and there may be only 1 or 2 of those. It is not unusual to see a niche market, especially one that requires a middle person, to disappear quickly or have wide fluctuations in process from one year to the next.

Producers need to pursue niche markets and possibilities for value added to their production. The Wilke project shows how important it is to remember that there are additional risks involved. The producer needs to have the financial, management, and time resources to pursue and meet the requirements of niche markets. The economic axiom that without risk there is no reward seems to be most applicable here. It is also true that higher risks also bring the potential of larger losses. Clearly knowing the risk capacity of the farm is even more critical in the area of alternative crops, niche markets, and value added pursuits.

Costing Method and Cost Assumptions. The key to the economic feasibility of the direct seed, intensive crop rotations explored in this project, is ultimately the difference between the revenues and the costs to produce those revenues. The most difficult part of the economic analysis of a project of this type is developing and assigning the costs of generating that revenue. The key to realistic comparisons of the economics of the systems is how close are our estimates of the production costs to what would actually be experienced if these cropping patterns using direct seed were used across the entire farm. The experimental design of the project used plot sizes large enough that normal farm equipment could be used. This resulted in plots on cooperators' farms of about 25 acres each, and due to the need of replication on the Wilke farm, about 10 acres each there. The challenge then becomes to take information from far less than farm size and translate it into information usable for comparison with whole farm information. Ultimately, the decision about the findings depends on how each producer uses the information to compare with his or her own operation and the accuracy of his or her cost information.

The economic analysis was neither intuitive nor straightforward. The old joke about economists needing 2 arms to make any decision, depending on the assumptions or potential conditions, is very true here. Yield, inputs used per acre, and input costs were straightforward to record and collect. Yet, a *usable* analysis of the economics of the crop rotations must include an allocation of equipment costs and labor, items for which cooperator data was not easily broken out for the plots.

Assumptions were needed about equipment usage as if the rotations were being used across the entire farm. The information needed to build the equipment use assumptions was collected from seven different farm operations with various land ownership and leasing patterns, very different equipment complements, and record systems.

Crop enterprise budgets are widely used to compare the costs and profitability of crop production within an agronomic growing area. The budgets are developed by estimating the costs of the equipment operations, fixed costs, land costs, return to management, etc., through an economic "engineering" process. The background information for that process is developed through the interview of a panel of producers who are brought together to discuss their operations, costs, equipment, and other aspects of their farm operations. The enterprise budget developer then creates a "representative" farm and develops operational costs around that farm size and the typical operations of that farm as shaped by the information provided by the panelists. The analysis used for this report modifies that process as identified below.

Rather than develop a “typical farm,” an analysis was engineered for each individual cooperator using specific yields, prices, input, and input costs derived from each individual plot. The equipment costs were engineered using cooperators' information to build equipment use assumptions. Information was provided by each cooperator on his or her equipment usage, maintenance experience, and field operations. We asked about equipment speed, breakdown experience, time down for small, in-field repairs, and other items influencing use efficiency of equipment. Additionally, information was provided about purchase price or present value of equipment if known. Area equipment and input dealers were surveyed on equipment values, fuel and maintenance cost estimates, such as typical time between overhauls of the engine on a particular model tractor, etc. One cooperator had very detailed records on all equipment costs and maintenance, and that information was used to shape our equipment maintenance assumptions. Since most of the direct seed drills were relatively new, maintenance costs were low. Discussions were held with longer-time direct seed operators and with equipment dealers to build a reasonable assumption about drill maintenance costs.

The actual calculation of the equipment costs was developed using a University of Idaho software program. The program, *Machine Cost* by LeRoy Stodick and Robert Smathers, Department of Agricultural Economics, University of Idaho, March 1994, uses industry standards and engineering information for the built-in equipment operation and cost parameters. Individual information can be substituted for the industry based parameters built into the program to generate equipment cost information more specific to an individual operation.

To create the equipment use assumptions we made another very large leap. The analysis assumes that the crop rotations in the plots were used across the entire farm. From this assumption, we would assign usage for the direct seed drill, spray rigs, fertilizer equipment if separate from the drill, and develop an annual hourly use for the tractors and combines. This is most critical in developing a cost estimate for the direct seed operations.

Assuming the application of the rotation across the entire farm is a very large assumption and likely far removed from reality as most farmers would make this transition in stages. The whole farm assumption seemed the only way to develop any reasonable estimate for the per acre costs of production.

One of the key cost items in the transition to direct seeding is the cost of the direct seed drill which, almost in every case, is much higher in price than the conventional drills they replace. It is also true that most direct seed drills take high horsepower tractors. The direct seeding costs per acre can vary dramatically depending on the number of acres a direct seed drill is used to seed annually, assuming the annual depreciation/replacement costs are allocated across the acres seeded in that year. The inverse is that each year's crop needs to pay for that portion of the equipment used that year. Normal practice has been to replace equipment when there was a good crop or price year. The authors believe that there will be fewer very good years in agriculture so capital replacement must be a regular part of the farm business plan.

Developing a way to reasonably allocate a cost for the direct seeding operation would make a difference on the final outcome of the economic analysis. A poorly utilized direct seed drill would cost significantly more on a per acre basis than all of the field operations it replaces in crop-fallow system; in fact, a highly utilized drill might still cost more than the field operations it replaces.

It was beyond the scope of this study to address the transition costs to direct seed which can be significant both in terms of learning how to manage the new production practices, weed management, marketing skills, and equipment costs. An added cost during the transition comes from utilizing 2 very different kinds of equipment complements, each at less than the optimal amount. This is less a problem cost wise for conventional equipment, much of which has been depreciated out and has little resale value, especially as the transition to direct seeding accelerates. The key issue is the underutilization of the new direct seed drill which can cost from $50,000 to close to $100,000, depending on size, air carts, etc.

The development of the equipment costs for this project assumes that the transition has been made to direct seed. We did not consider the cost of maintaining surplus equipment or a dual equipment complement, an item that any farmer making the transition should consider, especially if he or she is still making payments on conventional tillage implements that are not used in direct seed operations. Another possible cost not considered was the possible rapid depreciation in value of certain direct seed drills as new, better models are introduced that meet area conditions.

The focus of the economic analysis are the variable costs including *all* equipment costs. Variable production costs are those costs which change depending on whether a crop is planted or not and what crop is planted. The analysis does not consider net rent or return on the land investment, returns to management, and other findings involving inclusion of fixed costs, returns on investment, or borrowed capital costs (interest on replacement costs for equipment being the exception). These are costs which vary widely from farm to farm depending on location, debt, production, and other variables. Our sample size was too small to make any generalizations about these costs, and an individual farm situation could have skewed the finding. The need for confidentiality on debt would have been impossible to keep given this small sample size. To put these omissions in perspective, interest on operating capital and overhead would likely run another $8 to $17 an acre. Net land rent, a proxy for an expected return on land investment, would run from $15 to $40 an acre, depending on the productivity of the land in question. (WSU crop enterprise budgets, various years).

To use all equipment costs as variable costs, all equipment costs, fixed and variable, were translated into a variable, per hour of use basis. We assumed that a piece of equipment had a finite life in hours of use before overhaul was required. The cost of each of those hours are consumed as a variable cost including allocating annual maintenance and depreciation/replacement, and interest costs to each of those hours used. Key information we gathered from each cooperator were the number of hours each tractor and combine were used, purchase prices, or if fully depreciated out, a replacement cost was found by calling several equipment dealers in the area. These prices were updated annually. Maintenance costs, interest rates, equipment speed, width, and fuel and oil prices were gathered. All of this information was used to modify the engineered parameters in the *Machine Cost* program.

The exception to this was harvest trucking costs. The truck fleet being used by most cooperators was fully depreciated out (i.e., older trucks), had low mileage use each year, and maintenance costs were difficult to obtain. Since the trucking costs for most crops would not be different than the harvest trucking costs, i.e., field to elevator or farm storage, in the area, a trucking cost was derived from enterprise budgets previously published by WSU. Table 9 shows the results for 1 year of the 4-year rotation on the Wilke farm and is typical of what was developed for each cooperator each year. This information was provided to each cooperator each year.

Table 9. Wilke Farm 1998 4-Year Rotation.

Crop	Sp Wheat		Millet		Sp Barley		Safflower	Average
	Alpowa		Colorado Red		Meltan		McKay Seed	
Variable Input Costs								
Seed	$ 11.00		$ 2.80		$ 9.10		$ 15.20	$ 9.53
Fert.	$ 31.70		$ 16.00		$ 19.87		$ 8.00	$ 18.89
Herbicide	$ 10.05		$ -		$ 10.70		$ -	$ 5.19
Insecticide								$ -
Fuel/Lube	$ 2.99		$ 2.43		$ 2.99		$ 2.43	$ 2.71
Total Variable Input Costs	$ 55.74		$ 21.23		$ 42.66		$ 25.63	$ 36.32
								$ -
*Labor	$ 4.41		$ 3.77		$ 4.41		$ 3.77	$ 4.09
								$ -
**Trucking	$ 4.88		$ 4.88		$ 4.88		$ 4.88	$ 4.88
								$ -
Equipment Costs (tractor, drill, harrow, sprayer, combine)								$ -
Replacement Cost	$ 18.49		$ 17.49		$ 18.53		$ 17.49	$ 18.00
Repairs/Maintenance	$ 8.01		$ 7.65		$ 8.01		$ 7.65	$ 7.83
Total Equip. Costs	$ 26.50		$ 25.14		$ 26.54		$ 25.14	$ 25.83
								$ -
Taxes/Housing	$ 3.20		$ 3.10		$ 3.20		$ 3.10	$ 3.15
								$ -
Yield	31.22 bu		596 #		1.44T		593#	$ -
Price	$2.67		$ 0.08		84/T		$0.08	$ 0.71
Revenue/acre	$ 83.36		$ 47.68		$ 120.96		$ 47.44	$ 74.86
								$ -
Revenue less variable input costs	$27.67		$26.45		$78.30		$21.81	$ 38.56
Revenue less variable cost+ labor+ Equipment + Trucking (Harvest Haul)	-$11.37		-$10.44		$39.27		-$15.08	$ 0.60

*Estimate developed from previous Wilke farm data.

List of Operations:								
	Herb Spray Seed/Fert. Herb Spray	Harvest Trucking	Seed/Fert. Trucking Harvest		Herb Spray Seed/Fert. Herb Spray	Harvest Trucking	Herb Spray Seed/Fert. Harvest	Trucking

Price Assumptions. A key source of area farmers' incomes during these low-price years were government payments. Most government payments have been decoupled from production. That is, the payment has no relationship to the amount produced in a given year nor does it relate to the price received that year. The exception being LDP’s (Loan Deficiency Payments) which are tied not only to prices and the government loan rate, but also to a farmer’s production. Our revenue data does not take into account government payments except for LDP’s as noted below.

Establishing the price received can be elusive especially when cooperators market over the year and co-mingle the grain from the plots with the rest of their production (yields are measured for each plot, at harvest, in the field using either a weigh wagon or large portable scales). As a result, our cereal grain price information is based on the local price at harvest plus the LDP if applicable which is in effect the county loan rate. For non-cereal grain crops for which there was no established market, the price was the actual price received. These included millet and sunflowers. Oil seed crops were priced at the contract price plus LDP if one was available and applicable.

Results. This was a systems research project. That is, our goal was to view each rotation in whole as a system. The hope being that the combined nature of the crops in the rotation would lead to synergism that would allow reduced weeds, diseases, risk management, and increases in yields of cereals grains following non-cereal crops due to disease repression. The profitability of the combined "whole" is what we were interested in. We present that summary next, but also make comparisons among individual crops.

Table 10 shows the average for each of the rotations for the 4 years of the project. In each year except 2000, the 3-year rotation did better than the 4-year rotation. In 2000, the difference was a cost issue as fertilizer and herbicide costs ran considerably higher in the 3-year rotation than in the 4-year rotation. Revenue in the 3-year rotation was higher, but the higher costs more than offset the revenue difference.

Table 10. Average of All 3- and 4-Year Rotations, 1998 - 2001

	1998		1999		2000		2001	
Variable Input Costs	Avg for 4 year Rotation	Avg for 3 year rotation	Avg for 4 year Rotation	Ave for 3 year rotation	Avg for 4 year Rotation	Avg for 3 year rotation	Avg for 4 year Rotation	Avg for 3 year rotation
Seed	$ 10.29	$ 11.00	$ 11.94	$ 13.59	$ 10.56	$ 11.97	$ 13.60	$ 16.26
Fertilizer	$ 21.46	$ 23.59	$ 14.68	$ 17.32	$ 15.29	$ 19.89	$ 22.25	$ 22.71
Herbicide	$ 9.41	$ 15.20	$ 14.16	$ 23.60	$ 16.23	$ 26.08	$ 19.73	$ 27.21
Insecticide			$ 1.41	$ 0.64	$ 1.38	$ 0.62		
Custom	$ 1.20	$ 2.00		$ 0.27	$ 3.23	$ 4.13	$ 1.25	$ 2.50
Fuel/Lube	$ 3.39	$ 2.34	$ 4.84	$ 5.33	$ 5.37	$ 4.50	$ 3.34	$ 3.54
Total Variable Input Costs	$ 45.75	$ 54.13	$ 46.62	$ 60.72	$ 52.05	$ 67.18	$ 60.17	$ 72.22
*Labor	$ 5.12	$ 3.77	$ 3.46	$ 3.06	$ 3.59	$ 3.49	$ 3.22	$ 2.94
**Trucking	$ 4.88	$ 4.88	$ 4.88	$ 4.88	$ 4.88	$ 4.88	$ 4.88	$ 4.88
Equipment Costs (Tractor, drill, harrow, sprayer, combine)								
Replacement Cost	$ 17.65	$ 13.61	$ 19.75	$ 16.36	$ 21.28	$ 17.62	$ 18.42	$ 18.91
Repairs/Maintenance	$ 6.20	$ 5.64	$ 7.51	$ 7.38	$ 4.12	$ 5.70	$ 7.86	$ 9.76
Total Equip Costs	$ 23.85	$ 19.25	$ 27.26	$ 23.74	$ 25.40	$ 23.31	$ 26.28	$ 28.66
Taxes/Housing	$ 2.69	$ 2.29	$ 3.02	$ 2.13	$ 2.96	$ 2.27	$ 2.84	$ 3.28
Revenue/acre	$ 89.05	$ 94.14	$ 84.00	$ 99.69	$ 98.44	$102.55	$ 66.57	$ 102.43
Revenue less variable input	$ 43.31	$ 39.98	$37.39	$39.28	$50.75	$ 35.37	$ 12.18	$ 30.22
Revenue less variable cost+ labor+ Equipment + Trucking (Harvest Haul)	**$ 6.76**	**$ 9.85**	**-$1.22**	**$5.25**	**$17.02**	**$5.03**	**-$23.91**	**-$9.54**

* Labor calculated at $10 per hour, primarily operating time for field equipment

**Trucking cost "engineered"/ estimated from area enterprise budgets.

In general, cereal grains performed better financially than the non-cereals in the rotations (Table 11). There were 2 individual year crops of non-cereal grains that performed well, Canola in 1998, when it was grown only by 1 cooperator, and buckwheat in 1999. It was grown only 1 year and had a very small niche market that was developed by that cooperator. These niches are available and require developing marketing skills beyond those used in commodity marketing. In general, producing crops for which there is no developed marketing channel is a riskier proposition, but this was one example of success. Our millet was an example in frustration, both in production and marketing.

Table 11. Net Results for Individual Crops, Average across Years.

CROP	# of Years In Project	Revenue less Variable Input Costs (Average)	Revenue less Variable Input Costs, Labor, Equipment & Harvest (Average)
Winter Wheat	4	$73.69	$53.55
Spring Wheat	4	$56.37	$20.28
Spring Barley	4	$44.44	$8.60
Canola	4	$42.81	$3.00
Millet	4	$6.12	($32.05)
Mustard	2	$22.27	($16.48)
Peas	2	($26.99)	($63.79)
Sunflower	2	$18.58	($18.99)
Safflower	1	$0.36	($29.40)
Buckwheat	1	$92.41	$50.30
Corn	1	($40.67)	($79.67)
Flax	1	$26.50	$6.35
Oats	1	$10.30	($35.36)

The 4-year rotation had more non-cereals in the rotation, which lowered the net returns for the rotation. Warm season grasses, whether millet or corn, did not perform well and as the 4-year rotation included a warm season grass, which brought down the average for the rotation. One hypothesis of the rotations was that following 2 years out of cereals, there should be a rise in the production of the following cereal grain due to disease depression. This phenomenon did not appear in the data with the exception of wheat following sunflowers and the increase was not enough to offset the financial loss from the sunflowers so a net loss was realized. One observation based on the conditions present during this project is that the dominance of cereal grains in eastern Washington is not the result of irrational economic decisions.

In the absence of any measurable economic benefits to wheat and barley following 2 years out of cereals production, the information in Table 10 suggests that at most, 1 year out of 3 should be in a non-cereal crop. This, of course, would change if the profitability of the non-cereals were to improve. An unpublished report on oil seed production south of our project area, but in a similar rainfall zone, where yields were considerably better than ours and prices higher, indicate that even with higher yields and higher oil seed prices, only one of the 15 producers participating had raised an oil seed crop profitably (Hinman et. al, 2003).

There was wide variety in yields within years and across years. In 1998, spring wheat yields varied across cooperators between 31 and 50 bushels an acre (Tables 12A-12B). Spring barley yields varied from 1.36 tons per acre to 1.94 tons per acre. Millet yields varied between 400 and 800 lbs. per acre. Canola ranged in yield from 840 lbs. per acre in 2001, to 1570 lbs. per acre in 1998 (Tables 13 through 15). The 1998 canola crop price was $0.11 per pound and had the largest net over variable costs of any of the individual crops in any year. The average over the 4 years though was only $3 per acre, best of any of the other oil seed crops, but still well below the cereal grains. Since each faced roughly the same price in a given year (something that held true for the years in question, but might not in years with more price variation), the cooperators generated very different revenues from similar crops. The issue then for each producer is the net between the costs and those revenues.

The same was true for all years with a spread in input costs, primarily fertilizer and herbicides, between producers. The fertilizer differences reflect different application rates depending on yield expectations. Yield expectations are higher with a higher rainfall average, lower in traditionally dryer areas. The prices individual farmers are able to negotiate for inputs depends on the amount they purchase and whether they have their own application equipment. The spread in herbicide costs was primarily caused by timing issues, spraying too early and needing to spray again, or having to use extra sprays to compensate for the lack of effective weed control in a preceding crop for which there had been no registered herbicide. Until weed populations are stabilized, an assumption that will happen over time with direct seed and using different rotations, it is difficult to make firm conclusions about the economics of the system. As identified in the main project report, weed population changes were noted, but we had not experienced any stability in those populations nor were there clear conclusions that could be drawn about weed control, a significant cost of production.

Table 12A. 1998 Crops, Average Costs and Revenues, and Range of Costs and Revenues.

Variable Input Costs	Spring Wheat	Range of Input Cost	Spring Barley	Range of Input Cost	Canola	Winter Wheat
Seed	$ 10.37	$9.1-11.00	$ 8.57	$7.7-9.10	$ 25.65	$ 10.40
Fert.	$ 28.54	20.93-31.70	$ 22.86	19.87-31.70	$ 20.93	$ 28.84
Herbicide	$ 10.59	10.05-11.72	$ 13.53	10.70-22.70	$ 5.05	$ 31.43
Insecticide						
Custom	$ 3.00	$ 12.00	$ 0.72	$ 2.88		
Fuel/Lube	$ 3.38	1.97-5.59	$ 2.48	1.97-2.99	$ 3.18	$ 1.76
Total Variable Input Costs	$ 55.90		$ 48.18		$ 54.81	$ 72.43
*Labor	$ 4.79	$3.28-7.69	$ 3.84	$3.28-4.41	$ 4.66	$ 3.37
**Trucking	$ 4.88		$ 4.88		$ 4.88	$ 4.88

Equipment Costs (tractor, drill, harrow, sprayer, combine)						
Replacement Cost	$ 15.75	10.46-21.96	$ 14.73	10.46-18.53	$ 17.39	$ 10.63
Repairs/Maintenance	$ 6.67	3.15-8.02	$ 5.70	3.15-8.01	$ 3.71	$ 3.37
Total Equip. Costs	$ 22.41		$ 20.42		$ 21.10	$ 14.00
Taxes/Housing	$ 2.48	1.44-3.11	$ 2.40	1.44-3.2	$ 2.22	$ 1.70
Yield	35.78 bu	31-49.72	1.54 T	1.36-1.94T	1570#	60.6 bu
Price	$ 2.67	2.60-2.7	84.25/T	84-85 T	$ 0.11	$ 2.77
Revenue/acre	$ 95.60		$ 130.12		$ 172.70	$ 167.87
Revenue less variable input costs	$39.71		$81.94		$117.89	$95.44
Revenue less variable cost+ labor+ Equipment + Trucking (Harvest Haul)	$4.61		$50.36		$85.03	$71.49

*Labor calculated at $10 per hour primarily operating time for field equipment.

**Trucking cost "engineered"/estimated from area enterprise budgets.

Table 12B. 1998 Crops, Average Costs and Revenues, and Range of Costs and Revenues (continued).

Variable Input Costs	Millet	Range of Input Cost	Mustard	Range of Input Cost	Safflower	Range of Input Cost	Oats
Seed	$ 4.53	1.75-9.04	$ 14.38	12.5-16.25	$ 13.38	11.55-15.20	$ 8.54
Fert.	$ 18.55	13-26.65	$ 27.38	14.75-40	$ 11.26	8-14.52	$ 29.85
Herbicide	$ 5.05	4.50-10.64	$ 10.33	9.16-11.50	$ 2.72	$ 5.44	$ 11.72
Insecticide							
Custom	$ 3.84	$ 11.50					
Fuel/Lube	$ 3.09	2.43-3.87	$ 3.70	2.71-4.68	$ 2.01	1.58-2.43	$ 5.59
Total Variable Input Costs	$ 34.72		$ 55.79		$ 29.37		$ 55.70
*Labor	$ 5.25	3.77-7.62	$ 5.33	4.09-6.57	$ 3.42	3.06-3.77	$ 7.69
**Trucking	$ 4.88	$ 4.88	$ 4.88		$ 4.88	$ 4.88	$ 4.88
Equipment Costs (tractor, drill, harrow, sprayer, combine)							
Replacement Cost	$ 18.38	16.98-20.66	$ 18.97	17.99-19.95	$ 13.75	10.01-17.49	$ 21.96
Repairs/Maintenance	$ 5.81	3.61-7.65	$ 7.55	7.26-7.83	$ 5.40	3.15-7.65	$ 8.02
Total Equip Costs	$ 24.19		$ 26.52		$ 19.15		$ 29.98
Taxes/Housing	$ 2.88	2.18-3.35	$ 3.00	2.85-3.15	$ 2.37	1.63-3.10	$ 3.11
Yield	598.7#	400-800#	531.5#	513-550#	346.5#	100-593#	1650#
Price	$ 0.07	.07-.08	$ 0.125	0.125	$ 0.11	.081-.12	$ 0.04
Revenue/acre	$ 43.89		$ 66.44		$ 29.72		$ 66.00
Revenue less variable input costs	$9.18		$10.58		$0.36		$10.30
Revenue less variable cost+ labor+ Equipment + Trucking (Harvest Haul)	-$28.02		-$29.06		-$29.40		-$35.36

*Labor calculated at $10 per hour primarily operating time for field equipment.

**Trucking cost "engineered"/estimated from area enterprise budgets.

There were only 3 times in the rotations that non-cereal grains showed a positive return above our version of variable costs during the Canola in 1998 (grown all 4 years), flax in 2000 (only year), and buckwheat in 1999 (1 year only). The individual years for each crop are shown in Tables 12A&B above and Tables 13A&B, 14A&B, 15A&B below. The across-year average for crops is shown in Table 11 above. Spring wheat had positive returns above variable costs in each of the years and averaged $20.28 above variable costs. Barley was positive all years except 2001 when exceptionally high herbicide costs were experienced on the Wilke Farm because of spray timing issues. The 4-year average was $8.60 above variable costs. Winter wheat (re-cropped) showed positive returns each year it appeared in the rotation, averaging the highest of any individual crop at $53.55 an acre above variable costs.

While land costs, returns to management, fixed costs except for equipment were not calculated, using information from other studies cited earlier, no practical combination of crops in a 4-year or 3-year rotation would have showed returns adequate to fully cover all costs. The average for the 3- and 4-year rotations as shown in Table 10, show negative returns in 2001 for both rotations, and in 1999 for the 4-year rotation. Across the 4 years, revenues per acre would have to have increased on average some $40 to $50 an acre to cover total farm costs.

On average, across the project, this would mean wheat prices in the $4 to $4.25 a bushel range or some combination of increased yields and prices. Non-cereal grain yields in general were disappointing. Lack of rain and heat during key periods was primarily responsible. Whether this is a short-time phenomenon or longer-term pattern is not known. The spring rains are critical to the success of any spring crop, but especially the non-cereal grain crops. The yields experienced during the project are below area expectations and those experienced and recorded in other studies in the area. The Hinman et al., 2003 oilseeds study, with both higher yields and higher prices, does not provide much more optimism though for the oilseeds in the rotation.

Table 13A. 1999 Crops, Average Costs and Revenues, and Range of Costs and Revenues.

Variable Input Costs	Spg Wheat	Range of Input Cost	Spg Barley	Range of Input Cost	Canola	Range of Input Cost	Winter Wheat
Seed	$ 9.13	8.66-9.8	$ 9.40	6.30-10.95	$ 31.05	25-40.91	$ 8.65
Fert.	$ 15.09	10.75-20.13	$ 16.31	14.88-19.16	$ 20.94	18.29-25.37	$ 20.12
Herbicide	$ 20.15	7.18-36.34	$ 27.35	9.36-36.34	$ 15.76	5.94-23.97	$ 15.84
Insecticide					$ 6.92	3.81-16.95	
Custom					$ 0.53	$ 1.58	
Fuel/Lube	$ 4.70	3.49-6.46	$ 5.37	3.2-6.46	$ 5.49	4.93-6.46	$ 4.15
Total Variable Input Costs	$ 49.07		$ 52.36		$ 80.68		$ 48.76
*Labor	$ 2.98	2.18-3.91	$ 3.49	2.65-3.91	$ 3.17	2.46-3.91	$ 2.34
**Trucking	$ 4.88	$ 4.88	$ 4.88	$ 4.88	$ 4.88	$ 4.88	$ 4.88
Equipment Costs (tractor, drill, harrow, sprayer, combine)							
Replacement Cost	$ 16.56	12.5-19.22	$ 19.66	19.22-20.55	$ 22.89	15.51-33.94	$ 13.11
Repairs/Maintenance	$ 7.13	3.55-8.69	$ 7.25	4.56-8.6	$ 9.11	6.99-11.73	$ 3.92
Total Equip. Costs	$ 23.69		$ 26.92		$ 32.00		$ 17.03
Taxes/Housing	$ 2.42	1.15-3.04	$ 2.87	2.54-3.04	$ 3.15	1.31-5.11	$ 1.23
Yield	35.95 bu	29.8-48.5 bu	1.38 T	1.21-1.72T	1020.67	1000-1051	54 bu
Price	$ 2.79		70.53 T		.07/#		$ 2.77
Revenue/acre	$ 100.08		$ 97.75		$ 74.30		$ 149.58
Revenue less variable input costs	$51.02		$40.46		-$6.21		$100.82
Revenue less variable cost+ labor+ Equipment + Trucking (Harvest Haul)	$17.05		$2.30		-$49.58		$75.34

*Labor calculated at $10 per hour primarily operating time for field equipment.

**Trucking cost "engineered"/estimated from area enterprise budgets.

Table 13B. 1999 Crops, Average Costs and Revenues, and Range of Costs and Revenues (continued).

Variable Input Costs	Millet	Range of Input Cost	Mustard	Buckwheat
Seed	$ 5.25	4.00-7.88	$ 16.25	$ 8.00
Fert.	$ 12.81	8.52-19.16	$ 8.52	$ 10.75
Herbicide	$ 9.30	4.68-12.03	$ 11.20	$ 4.68
Insecticide				
Custom				
Fuel/Lube	$ 4.67	3.2-5.77	$ 5.77	$ 5.03
Total Variable Input Costs	$ 32.16		$ 41.74	$ 28.46
*Labor	$ 3.75	2.87-4.83	$ 3.56	$ 4.83
**Trucking	$ 4.88	$ 4.88	$ 4.88	$ 4.88
Equipment Costs (tractor, drill, harrow, sprayer, combine)				
Replacement Cost	$ 18.80	17.84-19.98	$ 18.57	$ 19.98
Repairs/Maintenance	$ 7.22	4.65-9.12	$ 7.88	$ 9.12
Total Equip. Costs	$ 26.01		$ 26.45	$ 29.10
Taxes/Housing	$ 2.95	2.57-3.30	$ 2.97	$ 3.30
Yield	872#	486-1080#	757#	1051#
Price	$ 0.06		.1/#	.115/#
Revenue/acre	$ 47.96		$ 75.70	$ 120.87
Revenue less variable input costs	$15.81		$33.96	$92.41
Revenue less variable cost+ labor+ Equipment + Trucking (Harvest Haul)	-$21.80		-$3.90	$50.30

*Labor calculated at $10 per hour primarily operating time for field equipment.
**Trucking cost "engineered"/estimated from area enterprise budgets.

Table 14A. 2000 Crops, Average Costs and Revenues, and Range of Costs and Revenues.

Variable Input Costs	Spring Wheat	Range of Input Cost	Spg Barley	Range of Input Cost	Canola	Winter Wheat	Range of Input Cost
Seed	$ 8.69	8.17-10.00	$ 9.40	7.44-12.00	$ 13.38	$ 9.48	8.43-10.00
Fert.	$ 21.07	17.86-23.97	$ 21.74	17.86-28.95	$ 20.02	$ 19.84	18.37-22.78
Herbicide	$ 17.61	7.40-44.88	$ 25.58	8.45-44.88	$ 19.65	$ 27.37	11.79-35.16
Insecticide					$ 8.46		
Custom	$ 0.75	$ 3.00	$ 1.00	$ 3.00	$ 15.75	$ 9.33	$ 14.00
Fuel/Lube	$ 6.96	3.30-8.39	$ 4.98	3.30-7.76	$ 3.30	$ 1.93	1.42-2.96
Total Variable Input Costs	$ 55.28		$ 62.69		$ 80.56	$ 67.95	
*Labor	$ 4.35	4.21-4.45	$ 4.19	3.92-4.45	$ 4.45	$ 2.00	1.21-3.57
**Trucking	$ 4.88		$ 4.88		$ 4.88	$ 4.88	
Equipment Costs (tractor, drill, harrow, sprayer, combine)							
Replacement Cost	$ 25.20	23.11-26.24	$ 21.18	15.24-25.19	$ 23.11	$ 12.11	11.18-13.97
Repairs/Maintenance	$ 4.05	2.30-7.49	$ 5.59	4.09-7.49	$ 4.09	$ 4.20	3.85-4.90
Total Equip. Costs	$ 29.24		$ 26.77			$ 16.31	
Taxes/Housing	$ 3.64	3.35-3.76	$ 3.08	2.20-3.68	$ 3.35	$ 1.90	1.82-2.07
Yield	49.59 bu	45-53 bu	1.74 T	1.4-2.36 T	1528#	51.19 bu	46-54.17 bu
Price	$ 2.84		73.33/T		$ 0.075	$ 2.84	
Revenue/acre	$ 140.82		$ 127.60		$ 114.60	$ 145.39	
Revenue less variable input costs	$85.54		$ 64.90		$34.35	$77.43	
Revenue less variable cost+ labor+ Equipment + Trucking (Harvest Haul)	$43.44		$5.98		-$5.53	$52.34	

*Labor calculated at $10 per hour primarily operating time for field equipment.

**Trucking cost "engineered"/estimated from area enterprise budgets.

Table 14B. 2000 Crops, Average Costs and Revenues, and Range of Costs and Revenue (continued).

Variable Input Costs	Millet	Range of Input Cost	Peas	Sunflowers	Range of Input Cost	Flax
Seed	$ 4.09	2.40-7.00	$ 30.00	$ 25.00	$ 25.00	$ 3.97
Fert.	$ 11.51	6.97-13.99	$ 8.38	$ 10.75	7.50-13.99	$ 23.00
Herbicide	$ 9.42	5.28-12.96	$ 18.22	$ 30.46	6.76-30.46	$ 23.01
Insecticide			$ 3.68	$ 4.05	$ 8.10	
Custom	$ 1.00	$ 3.00	$ 7.75	$ 1.50	$ 3.00	
Fuel/Lube	$ 5.51	3.07-7.76	$ 7.76	$ 7.52	6.11-8.92	$ 3.20
Total Variable Input Costs	$ 31.53		$ 75.79	$ 67.42		$ 53.18
*Labor	$ 3.77	3.02-4.21	$ 4.21	$ 4.19	3.21-5.16	$ 3.81
**Trucking	$ 4.88		$ 4.88	$ 4.88		$ 4.88
Equipment Costs (tractor, drill, harrow, sprayer, combine)						
Replacement Cost	$ 22.33	18.79-25.24	$ 25.19	$ 26.59	19.60-33.57	$ 14.92
Repairs/Maintenance	$ 4.38	1.65-7.49	$ 7.49	$ 6.04	1.86-10.21	$ 5.23
Total Equip. Costs	$ 26.70		$ 32.68	$ 36.62		$ 20.15
Taxes/Housing	$ 2.64	1.65-3.33	$ 1.65	$ 3.98	2.93-5.03	$ 2.17
Yield	508 #	174-850 #	791.64#	1076 #	1000-1152	960#
Price	$ 0.06	0.06	.055/#	.06/#	.04-.08***	.083/#
Revenue/acre	$ 32.15		$ 43.54	$ 63.03		$ 79.68
Revenue less variable input costs	-$1.04		-$32.25	-$2.42		$ 26.50
Revenue less variable cost+ labor+ Equipment + Trucking (Harvest Haul)	-$38.43		-$64.93	-$38.56		$ 6.35

*Labor calculated at $10 per hour primarily operating time for field equipment.

**Trucking cost "engineered"/ estimated from area enterprise budgets.

*** $0.04 is an estimate as sunflowers were used for hog feed when no market was available.

Table 15A. 2001 Crops, Average Costs and Revenues, and Range of Costs and Revenue.

Variable Input Costs	Spring Wheat	Range of Input Cost	Spring Barley	Canola	Range of Input Cost	Winter Wheat	Range of Input Cost
Seed	$ 10.75	8.51-16.00	$ 11.00	$ 17.68	16.55-18.80	$ 10.54	8.13-11.87
Fert.	$ 25.29	23.50-28.51	$ 28.21	$ 23.84	23.06-24.61	$ 30.57	19.61-39.02
Herbicide	$ 24.72	12.00-32.48	$ 39.60	$ 14.56	7.43-21.69	$ 29.25	7.63-42.00
Insecticide							
Custom	$ 1.50	$ 7.50	$ 7.50			$ 3.75	0-7.50
Fuel/Lube	$ 2.98	2.39-3.75	$ 2.39	$ 4.21	3.75-4.67	$ 2.98	2.39-3.75
Total Variable Input Costs	$ 65.18		$ 88.70	$ 60.28		$ 77.08	
*Labor	$ 2.86	2.15-4.04	$ 2.15	$ 4.53	3.25-5.81	$ 2.83	2.15-3.77
**Trucking	$ 4.88		$ 4.88	$ 4.88		$ 4.88	
Equipment Costs (tractor, drill, harrow, sprayer, combine)							
Replacement Cost	$ 17.32	14.95-18.99	$ 18.01	$ 22.21	18.81-25.61	$ 18.27	18.01-18.81
Repairs/Maintenance	$ 9.69	2.68-13.35	$ 6.98	$ 7.94	3.68-12.20	$ 7.16	2.47-12.20
Total Equip. Costs	$ 27.01		$ 24.99	$ 30.15		$ 25.43	
Taxes/Housing	$ 2.74	2.26-3.35	$ 3.06	$ 3.57	3.35-3.79	$ 3.02	2.6-3.35
Yield	37.89	30.94-56	1.02 T	840.00	755-925#	38.99 BU	32.77-46.5
Price	$ 3.34	3.23-3.45	82/T	$ 0.110	.1-.11	$ 3.29	3.25-3.30
Revenue/acre	$ 126.42		$ 83.64	$ 85.50		$ 128.15	
Revenue less variable input costs	$61.25		-$5.06	$25.21		$51.07	
Revenue less variable cost+ labor+ Equipment + Trucking (Harvest Haul)	$23.75		-40.14	-$17.92		$15.02	

*Labor calculated at $10 per hour primarily operating time for field equipment.

**Trucking cost "engineered"/estimated from area enterprise budgets.

Table 15B. 2001 Crops, Average Costs and Revenues, and Range of Costs and Revenue (continued).

Variable Input Costs	Millet	Range of Input Cost	Peas	Range of Input Cost	Sun-flower		Corn
Seed	$ 2.75	2.50-3.00	$ 34.00	$ 34.00	$ 25.00		$ 20.00
Fert.	$ 21.48	18.35-24.61			$ 11.00		$ 25.00
Herbicide	$ 5.95	5.00-6.90	$ 16.40	$ 16.40	$ 28.00		$ 18.00
Insecticide							
Custom							
Fuel/Lube	$ 4.00	3.38-4.61	$ 5.17	$ 5.17	$ 2.67		$ 2.67
Total Variable Input Costs	$ 42.85		$ 55.57	$ 55.57	$ 66.67		$ 65.67
*Labor	$ 3.29	2.8-3.77	$ 3.59	$ 3.59	$ 2.55		$ 2.55
**Trucking	$ 4.88		$ 4.88	$ 4.88	$ 4.88		$ 4.88
Equipment Costs (tractor, drill, harrow, sprayer, combine)							
Replacement Cost	$ 19.36	18.26-20.45	$ 20.97	$ 20.97	$ 15.85		$ 15.85
Repairs/Maintenance	$ 5.12	2.47-7.76	$ 7.99	$ 7.99	$ 13.35		$ 13.35
Total Equip. Costs	$ 24.47		$ 28.96	$ 28.96	$ 29.20		$ 29.20
Taxes/Housing	$ 3.02	2.6-3.44	$ 34.00	$ 34.00	$ 2.37		$ 2.37
Yield	578 #	356-800 #	541.5 #	541-542	850 #		500#
Price	*.06		$0.0625		0.125		.05/LB
Revenue/acre	$ 34.68		$ 33.85		$ 106.25		$ 25.00
Revenue less variable input costs	$0.51		-$21.72		$ 39.58		-$40.67
Revenue less variable cost+ labor+ Equipment + Trucking (Harvest Haul)	-$35.40		-$62.65		$ 0.58		-$79.67

Lessons Learned and Observations

Risk Management. The results of this project indicate that the introduction of non-cereal grain crops increases the risks of both price and yield to the farm. The hoped-for price risk mitigation from diversifying the cropping base was not experienced during this project as all prices were depressed at the same time. Yield risk from lack of moisture and heat to the non-cereal grains appears to be greater than to the cereal grains that are adapted to this area. Wheat and barley continued to be the least-risk crops and while prices were very low, their returns over costs were still above all viable alternatives.

Benefits to Wheat following Alternatives. Again, with the exception of sunflowers, the project did not identify any measurable increases in yields in wheat following a non-cereal grain crop. The losses associated with the sunflowers took away any possible gain from the increased production of wheat following the sunflowers. Given the increased risk introduced to the farm from the non-cereal grain crops, other alternatives should be explored. One issue not explored was whether the farm would be better off with canola or chemical fallow in the 3-year rotation. Canola appears to have the highest probability of profitability of any of the alternative crops but it was not compared with the costs of a chemical fallow in the 3-year rotation. The expectation with chemical fallow is/was that weed population improvements could be made with chemical fallow. (This was being tested in 2000.) It should be noted that there are producers in the area who have produced canola profitably for years. It should also be noted that there is no certainty in prices. Using 3 cereals in a 4-year rotation also has merit although this study was not long enough to make a sound analysis of that option. The low price patterns experienced during the project hopefully will not repeat themselves.

Crops for Which There Are No Developed Marketing Channels. Growing crops for which there are no developed marketing channels introduces increased costs and much higher price risks to the farm. Farm managers should consider these alternatives only after carefully exploring the marketing possibilities and identifying a market. It would be wise to wade in rather than jump in with crops with no developed market channels. While niche markets offer the potential for higher returns to the farm, farms should carefully ascertain if the time to pursue these markets is available. A key factor will be whether there are available within the management team the skills necessary to negotiate price, quality, delivery, guaranteed payment on delivery, etc. There often are additional transportation costs for not well-developed markets as the delivery point may be several hundred miles away. Many of the costs associated with niche markets are non-cash costs, primarily time. Farming is no different from any other part of 21st century business and living; time is the commodity. Research on crops for which there are no marketing alternatives should be confined to small plot work.

Warm Season . The theory behind bringing a warm season grass into the rotation was that it would allow later planting and therefore give additional weed control options. The highly negative economics of the warm season grasses leads to the conclusion that it is impossible to imagine any set of benefits that would justify the economic drain on the resources of the farm that the warm season grasses represent at this time. An analysis of rainfall patterns in May and June, back over time is necessary to measure the odds of success of crops requiring those late spring rains.

Management Complexity. By introducing so many new items into the equation all at once, success in each area was made more difficult. This project introduced several items that increased the managerial complexity of the farm operation. The first was the new technology of direct seeding and while some of the cooperators had had some experience with direct seeding, it was relatively new for all.

Combining direct seedingwith annual cropping and new crops brings a whole host of new variables into the decision-making matrix. An analogy is that the traditional wheat, barley, fallow, or wheat fallow system was like keeping 3 balls in the air simultaneously. The new direct seed annual cropping system with so many new crops requires keeping many more balls in the air at the same time. It is possible, but requires more intensity and skills than the 3-ball system.

Direct Seed. Many of the questions through the life of the project have been around direct seeding issues. It can be done successfully as a number of farmers in the area are making direct seed work. There were so many variables introduced through the many crops and various rotations of the Wilke project, a clear conclusion about the profitability of direct seeding cannot be made from this data. The economic data from the cereal grain production suggests that direct seeding clearly is highly probable to be successful. An area for further research is how to bring the weeds under control in the system. The application of direct seed technology is likely to accelerate the restructuring of dryland agriculture as farmers who learn the direct seed techniques will seek additional acreage to fully utilize the direct seed drill so as to spread the cost of the drill and tractor over as many acres as possible.

<u>Observations and Conclusions.</u> Replacing winter wheat with a spring crop introduces increased risk into the farming operation. The economic success on the Wilke project with recrop winter wheat (as measured by highest returns over costs) would suggest that in the intermediate rainfall area, removing the fallow year is a strong option. The key issue is identifying the crop to use in place of fallow.

There are a new set of issues and problems to solve with direct seed/annual cropping. Equipment utilization is one of the keys to keep the costs of direct seeding competitive. Very few farms go from no direct seed to total direct seed the following year. It is necessary to have the financial reserves to carry the farm through the transition. Drawing from the Wilke experience, the transition will be more costly farming; costly in time, additional risks, additional costs of equipment, and possibly lower yields and increased input costs. These risks are manageable, but that must be thought through while maintaining financial reserves.

No attempt was made to place an economic value on the environmental benefits from the rotations.

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APPENDIX A

Miscellaneous Agronomic Data Tables

Table A1. Wilke farm crops, varieties, and yields for 3- and 4-year crop rotations, 1998 to 2001.

		1998		1999		2000		2001		
Rotation	Crop Type	Crop (variety)	Yield	Crop (variety)	Yield	Crop (variety)	Yield	Crop (variety)	Yield	Average yield
			lb/a (bu/a)		lb/a (bu/a)		lb/a (bu/a)		lb/a (bu/a)	
3-year	Sm. grain	S. wheat (Alpowa)	1881 (32)	S. wheat (Calorwa)	2072 (35)	W. wheat (Rely)	3204 (53)	W. wheat (Mad/Elt)	2788 (46)	2377
	Sm. grain	Barley (Meltan)	2770	Barley (Meltan)	2440	Barley (Meltan)	2800 (47)	Barley (Baronesse)	2040 (34)	2309
	Broadleaf	Yellow Mustard	513	Yellow Mustard	757	Peas (Toledo)	792	Peas (Eiffel)	541	609
Total lb/a			5164		5269		6796		5369	
4-year	Sm. grain	S. wheat (Alpowa)	1866 (31)	S. wheat (Wawawai)	1784 (30)	S. wheat (Alpowa)	3080 (52)	S. wheat (Alpowa)	1856 (31)	2128
	Sm. grain	Barley (Meltan)	2940	Barley (Baronesse)	2433	W. wheat (Madson)	3250 (54)	W. wheat (Mad/Elt)	1966 (33)	2493
	Warm season grass	Proso Millet CO. Red	596	Proso Millet Early Bird	486	Proso Millet (Dawn)	174	Proso Millet (WSU-CH3)	357	741
	Broadleaf	Safflower	593	Canola (Hyola 308)	1011	Sunflower (Big Foot)	1151	Peas (Eiffel)	542	739
Total lb/a			5995		5714		7655		4721	

Table A2. Wilke farm residue production for 3- and 4-year crop rotations, 1998-2001.

		1998		1999		2000		2001		
Rotation	Crop Type	Crop (variety)	Residue	Crop (variety)	Residue	Crop (variety)	Residue	Crop (variety)	Residue	Average residue
			lb/a		lb/a		lb/a		lb/a	lb/a
3-year	Sm. grain	S. wheat (Alpowa)	4581	S. wheat (Calorwa)	4118	W. wheat (Rely)	4767	W. wheat (Mad/Elt)	10984	6397
	Sm. grain	Barley (Meltan)	5040	Barley (Meltan)	4710	Barley (Meltan)	4013	Barley (Barronesse)	10468	6150
	Broadleaf	Yellow Mustard	3063	Yellow Mustard	4897	Peas (Toledo)	4607	Peas (Eiffel)	5907	4760
4-year	Sm. grain	S. wheat (Alpowa)	5612	S. wheat (Wawawai)	6086	S. wheat (Alpowa)	7642	S. wheat (Alpowa)	4428	7706
	Sm. grain	Barley (Meltan)	4835	Barley (Barronesse)	5435	W. wheat (Madson)	5865	W. wheat (Mad/Elt)	10242	10355
	Warm season grass	P. Millet CO. Red	6466	P. Millet Early Bird	5771	P. Millet (Dawn)	5131	P. Millet (WSU-CH3)	--	
	Broadleaf	Safflower	6181	Canola (Hyola 308)	7809	Sunflower (Big Foot)	4467	Peas (Eiffel)	3778	4843

Table A3. Cooperator crops, variety, and yield for 3- and 4-year rotations.

Cooperator	Crop Type	1998		1999		2000		2001		Average Yield
		Crop (variety)	Yield	Crop (variety)	Yield	Crop (variety)	Yield	Crop (variety)	Yield	
			lb/a (bu/a)		lb/a (bu/a)		lb/a (bu/a)		lb/a (bu/a)	lb/a
3-1	Sm. grain	S. wheat (Edwall)	2040 (34)	S. wheat (Alpowa)	1800 (30)	S. wheat (Alpowa)	2568 (43)	W. wheat (Rely)	1800 (30)	2977
	Sm. grain	Barley (Camelot)	2760	Barley (Baronesse)	2400	Barley (Baronesse)	2520	Barley (Camelot)	1500	2812
	Broadleaf	Canola	1001	Canola (Reward)	517	Buckwheat[†]	--	Summer Fallow	--	455
3-2	Sm. grain	W. wheat (Madson)	3650	W. wheat (Eltan)	3240 (54)	W. wheat (Eltan)	2760 (46)	W. wheat (Coda)	2520 (42)	1977
	Broadleaf	Safflower	100	Canola (Hyola 308)	1078	Flax (McDuff)	960	Canola (IMC 015)	755	759
	Sm. grain	Barley (Harrington)	3000	S. wheat (Wawawai)	2580 (43)	Barley (Harrington)	2900	S. wheat (Winsom)	2340 (39)	2370
4-1	Sm. grain	S. wheat (Penawawa)	2983 (50)	S. wheat (Wawawai)	2910 (49)	S. wheat (Penewawa)	2940 (49)	W. wheat (Coda)	2100 (35)	3048
	Sm. grain	Barley (Baronesse)	3880	Barley (Baronesse)	3440	Barley (Baronesse)	4720	S. wheat (Penewawa)	3360 (56)	3535
	Warm season grass	Millet (CO. Red)	800	Millet (Dawn)	1050	Millet (Dawn)	850	Millet (WSU-CH3)	800	875
	Broadleaf	Canola (Hyola 308)	1570	Canola (Hyola 308)	1000	Canola (IMC 105)	1529	Canola (IMC 105)	925	906
4-2	Sm. grain	S. Wheat (Alpowa)	1860 (31)	S. wheat (Wawawai)	1980 (33)	S. wheat (Alpowa)	3180 (63)	S. wheat (Winsome)	1920 (32)	2183
	Sm. grain	Oats (Celsia	1650	S. wheat (Wawawai)	1650 (28)	S. wheat (Alpowa)	2700 (45)	S. wheat (926 R)	1860 (31)	2018
	Warm season grass	Millet (CO. Red)	400	Millet (Dawn)	1080	Millet (Dawn)	500	Corn Canamaize	500	680
	Broadleaf	Mustard (Yellow)	550	Buckwheat	1051	Sunflower (Integra 626)	1000	Sunflower (Integra 626)	860	865

[†] Buckwheat froze on Sept. 10, 2000, field not harvested.

Table A3. Cooperator crop residue for 3- and 4-year rotations.

Cooperator	Crop Type	1998		1999		2000		2001		Average Residue
		Crop (variety)	Residue	Crop (variety)	Residue	Crop (variety)	Residue	Crop (variety)	Residue	
			lb/a		lb/a		lb/a		lb/a	lb/a
3-1	Sm. grain	S. wheat (Edwall)	4243	S. wheat (Alpowa)	3896	S. wheat (Alpowa)	2642	W. wheat (Rely)	5593	4094
	Sm. grain	Barley (Camelot)	8020	Barley (Baronesse)	5941	Barley (Baronesse)	2402	Barley (Camelot)	6441	5701
	Broadleaf	Canola	4511	Canola (Reward)	4520	Buckwheat[†]	--	Summer Fallow	--	4516
3-2	Sm. grain	W. wheat (Madson)	8216	W. wheat (Eltan)	6971	W. Wheat (Eltan)	10270	W. wheat (Coda)	7545	8677
	Broadleaf	Safflower	4050	Canola (Hyola 308)	4744	Flax (McDuff)	7503	Canola (IMC 015)	8269	5225
	Sm. grain	Barley (Harrington)	5724	S. wheat (Wawawai)	4732	Barley (Harrington)	5845	S. wheat (Winsom)	6019	5858
	Broadleaf	Safflower	4050	Canola (Hyola 308)	4744	Flax (McDuff)	7503	Canola (IMC 015)	8269	5225
4-1	Sm. grain	S. wheat (Penawawa)	5975	S. wheat (Wawawai)	7488	S. wheat (Penewawa)	2852	W. Wheat (Coda)	7413	7413
	Sm. grain	Barley (Baronesse)	4382	Barley (Baronesse)	6142	Barley (Baronesse)	4740	S. wheat (Penewawa)	6037	5669
	Warm season grass	Millet (CO. Red)	4963	Millet (Dawn)	5632	Millet (Dawn)	4136	Millet (WSU-CH3)	8853	4910
	Broadleaf	Canola (Hyola 308)	9948	Canola (Hyola 308)	5720	Canola (IMC 105)	5547	Canola (IMC 105)	8437	7413
4-2	Sm. grain	S. wheat (Alpowa)	8430	S. wheat (Wawawai)	6565	S. wheat (Alpowa)	6695	S. wheat (Winsome)	10570	7244
	Sm. grain	Oats (Celsia	8539	S. wheat (Wawawai)	5554	S. wheat (Alpowa)	5371	S. wheat (926 R)	7176	7481
	Warm season grass	Millet (CO. Red)	6484	Millet (Dawn)	7368	Millet (Dawn)	6119	Corn Canamaize	6347	6580
	Broadleaf	Mustard (Yellow)	6671	Buckwheat	7246	Sunflower (Integra 626)	5320	Sunflower (Integra 626)	NC	6412

[†] Buckwheat froze on Sept. 10, 2000, field not harvested or residue collected, Cooperator 4-2, 2001 sunflower residue not collected.

APPENDIX B

Soilborne Pathogens and Root Diseases - Wilke Farm

Soilborne Pathogens and Root Diseases - Wilke Farm

No disease or pathogen measurements were made over the course of these rotation studies at the Wilke farm. However, in Fall 2003, soil samples were taken from the rotations at the end of the experiment. These samples were sent to Australia for DNA analysis by SARDI (South Australian Research and Development Institute) (Ophel-Keller 2003). This test provides a quantitative analysis of the pathogen populations in the soil, based on picograms DNA/g of soil. With this method, DNA is extracted from soil, and PCR primers specific to each pathogen are used to amplify the DNA. The following pathogens are detected by this test: *Gaeumannomyces graminis* var. *tritici* (take-all), *Rhizoctonia solani* AG8, (*Rhizoctonia* root rot), *Heterodera avenae* (cereal cyst nematode), *Pratylenchus neglectus*, and *P. thornei* (lesion nematode); *Fusarium pseudograminearum* and *F. culmorum* (Fusarium crown rot), and *Bipolaris sorokiniana* (common root rot).

We hypothesized that root diseases result from inoculum in the soil and residue, which are produced during the previous year(s) of cropping. These pathogens produce resistant spores (*Fusarium, Bipolaris*) or survive as mycelium in decaying roots (*Rhizoctonia, Gaeumannomyces*). This test also detects 3 important nematodes, cereal cyst nematode (*Heterodera*) and 2 species of lesion nematode (*Pratylenchus*).

It is well known that crop rotation will influence certain root pathogens, if one of the crops is a non-host or if there is no crop (fallow). During this unfavorable period for the pathogen, inoculum in the soil will decline over time due to microbial attack, feeding by soil invertebrates, or loss of energy through respiration. In any case, the inoculum level of certain pathogens will be reduced following crop rotation and fallow, and we hypothesized this test would detect these differences.

Methods and Materials

Soil samples were taken from 3 locations within each rotation strip of 8-10 acres. These locations were randomly chosen within the north, middle, and southern sections of the rotation strips. Three samples were taken from every rotation strip, and 9 replicated strips were sampled for the 3-year rotations and 12 replicated strips from the 4-year rotations. Approximately 1 kg of soil was dug from the upper 6 inches. Soil was air-dried and frozen at -20°C for 2 weeks before being sent to Australia. The freezing was a quarantine requirement to kill any insects in the soil.

Results were received in a spreadsheet as picograms DNA/g soil. DNA levels were log transformed after adding 1 to each of the values, in order to make the data normally distributed. ANOVA was performed using rotation and strips as main factors. Means were separated with LSD at P=0.05. If data was not normally distributed after transformation, means were separated with Kruskal-Wallis One-Way non-parametric ANOVA. Risk levels were also assigned to the values, based on Australian conditions, but may not be applicable to our conditions.

Results and Discussion

The take-all pathogen, *Gaumannomyces graminis* var *tritici*, was below detectable levels in all samples taken. This pathogen is normally not a problem in the normal 3- or 4-year rotations in eastern Washington that contain a non-host broadleaf crop (peas, chickpeas, lentils, canola, sunflower, safflower, buckwheat, flax), a fallow, or a non-host monocot (corn, oats, millet). This data fits the observations of numerous studies of this disease over the past 50 years. The cereal cyst nematode was not detected in any samples. This nematode is a problem in northeast Oregon and the Willamette Valley, but has not been detected in the dryland areas of Washington. *Pratylenchus neglectus*, the root lesion nematode, was only detected in 12 out of 63 samples, and was in low levels at those sites. *P. thornei*, the more virulent of the 2 species, was found in only 1 sample.

These nematodes have been implicated in yield losses on cereals in Oregon (Smiley, personal communication and submitted manuscripts). They have a wide host range, with wheat being the most preferred host, followed by barley. They can also reproduce on broadleaf crops, but there is variability among species and cultivars in terms of reproductive success. These rotation crops may have limited the buildup of these nematodes, but we cannot identify the effect of specific broadleaf crops in this experiment.

Surprisingly, *Rhizoctonia solani* AG-8 was not detected in most of the samples. It was only detected in 6 out of 63 samples, in low levels in 5 of those samples. This finding was surprising. Of all the soilborne pathogens, *Rhizoctonia solani* has the strongest evidence for increasing under direct-seeding conditions. This increase is often found early in the transition from conventional to direct-seeding (years 3-4 in studies by Schroeder, 2004, in Garfield, WA). But, in longterm direct-seeded fields, he did not find any differences, when compared with conventional tillage.

The Wilke farm may have transitioned to this more suppressive state regarding *Rhizoctonia*. However, this test detects only one AG group, AG-8. We have found other AG groups, specifically AG 2-1, which is pathogenic to brassicas. *R. oryzae* also causes root rot in the PNW, many isolates are highly virulent (Paulitz et al. 2003), and this pathogen would not be detected by this test.

The 3 pathogens, *F. culmorum, F. pseuodograminearum,* and *Bipolaris sorokiniana,* cause a crown, foot, and root rot complex. Most of the research in the PNW has focused on *Fusarium*, which is increased by plant drought stress and excessive nitrogen. *F. pseudograminearum* is more predominant in the low rainfall areas, and *F. culmorum* in the higher rainfall areas. This was supported by the data at the Wilke farm (Table 1), which agrees with other surveys in the Palouse area. This data indicates that *F. culmorum* is responsible for *Fusarium* crown rot at this site. It was found in low levels in 38 samples, medium levels in 15 samples, and high levels in 9 samples.

Table 1B. DNA levels of crown and foot rot pathogens in the soil of 3-year and 4-year rotations at the Wilke Farm, Fall 2003.

Rotation	*Fusarium pseudograminearum* (log pg DNA/g soil)	Risk	*Fusarium culmorum* (log pg DNA/g soil)	Risk	*Bipolaris sorokiniana* (log pg DNA/g soil)	Risk
3-year	0.41	Below detection	1.92	low	1.22	low
4-year	0.17	Below detection	1.66	low	0.39	Below detection
P value	0.03		NS		0.001	

On the other hand, *F. pseudogramineaum* was below the detection limit in 54 out of 63 samples. *Bipolaris sorokiniana* was detected in many of the samples. Although little research has been done on this pathogen in the PNW, surveys from 1994 indicated it was important in Adams, Lincoln, and Whitman counties (Smiley and Patterson 1996). It was also one of the predominant pathogens isolated from the roots in a survey in Idaho (Strausbaugh et al. 2004). At the Wilke farm, it was primarily associated with the 3-year rotation, found in 13 out of 27 samples, but only in 1 out of 36 samples in the 4-year rotation. Of the 13 positive samples in the 3-year rotation, 7 contained high levels of *Bipolaris,* and 2 contained medium levels.

The DNA concentration of *Bipolaris* was significantly higher in the 3-year rotation. This pathogen is found primarily on wheat, barley, and other temperate grasses, but corn and millet are also hosts. However, corn and millet may support lower populations of this pathogen on the crowns and stalks, which may be preferentially colonized by other fungi. This rotation effect will have to be examined further.

There was also a significant rotation effect on *F. pseudograminearum*, but not *F. culmorum*. *F. culmorum* produces thick-walled chlamydospores that can survive in the soil for longer periods than *F. pseudograminearum,* which survives in crop residue. This longevity would negate any rotation effect, since the pathogen could survive in the absence of a host. For *F. pseudograminearum,* higher levels were found in the 3-year rotation, which could be due to the effect of millet. However, the levels of this pathogen were so low that it would be unwise to speculate without data from fields with higher levels of the pathogen.

In conclusion, these results indicate that crown and foot rot caused by *Fusarium culmorum* and *Bipolaris sorokiniana* was the major disease on the Wilke farm. It was probably not in epidemic proportions that would be noticeable to growers and researchers. Above ground, this disease may cause whiteheads and reduced seed size, but only when the plant is heavily infected, as may occur during a drought year.

The symptoms of *Bipolaris* may be mistaken for *Fusarium* or *Rhizoctonia*, and this pathogen may be underestimated in the total disease complex of wheat in the PNW. *Bipolaris* was higher in the 3-year rotation, an interesting result which suggests the warm season grasses may support lower populations of this pathogen. The other pathogens (take-all, *Rhizoctonia solani* AG8, and root lesion nematodes) probably were not major yield-limiting factors. One should not discount the effects of pathogens that were not measured by these tests; *Rhizoctonia oryzae* and *Pythium* spp. With the exception of *Bipolaris,* there did not appear to be any major pathogen differences between the 3-year and 4-year rotation.

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