



FIGURE 6.1. *Field strips comparing production of direct seeded triticale, spring barley, hard red spring wheat, and durum wheat in an on-farm test on producer Jim Melville's farm in a 12-inch or higher annual precipitation area in Lincoln County. On-farm testing is a replicated, statistically-valid research approach with field trials established and managed by growers using their own farm equipment. The research approach has the advantage over traditional long-term field research by responding to growers' need for early information on impacts of implementing new management systems to address changes in farm policy, environmental concerns and economic conditions. Photograph by A. Esser, WSU Extension.*

# On-Farm Testing and Extension Outreach to Aid Adoption of Best Management Practices

### ON-FARM TESTING PROJECT

On-farm testing was initiated in 1998 under the leadership of A.D. Esser and R.J. Veseth, WSU Extension, as a subproject of the CP<sub>3</sub> to assist growers in conducting conservation management-related research on their own farms. Of primary interest was the inclusion and adaptation of minimum tillage and no-till farming practices to achieve more diverse cropping systems with the potential to improve profitability, erosion control and soil productivity in the 8 to 14-inch annual precipitation areas of the Columbia Plateau.

On-farm testing is a replicated, statistically-valid research approach with field trials established and managed by growers using their own farm equipment (Fig. 6.1). The tests are designed to measure the effects of crop or soil management practices, i.e., "treatments" (e.g., fertilizer, sowing rates and dates, tillage type, crop varieties, drill type or herbicide program) on crop production or farm economics (e.g., yields, pest infestations, net returns).

Treatments are generally imposed in long adjacent strips in widths that fit the grower's tillage, planting or harvesting equipment, and are randomly mixed within a replication or block. Four replications with a minimum of three treatments are recommended in most experimental layouts to provide adequate precision to separate treatment effects. Ideally, the individual field strips are 750 feet or longer to minimize the effects of soil or slope variability on treatments (Esser, 1998).

The project provides technical assistance to growers for developing an experimental plan, providing recommendations for cultural practices, and with sampling, harvesting, analyzing data and interpreting and reporting results. Field monitoring is conducted

to assess progress of the work. Information from the experimental results is evaluated and disseminated as a part of the extension education effort through field tours, reports, and grower education meetings.

This experimental approach enables growers to achieve statistical precision comparable to that for replicated, small-plot field trials; moreover because of natural within-field variability on most land, adequate replication is essential for making valid comparisons of treatment effects. The on-farm testing project has portable weighing equipment available for accurate and rapid measurement of grain yields that markedly reduces time and labor in harvesting the crop samples. On-farm tests are often site and season specific, and unless repeated for several years they do not account for effects of weather variability on soil and crop responses to treatments. However, data obtained from different test sites over several years may be analyzed to separate the effects of a specific treatment from that of weather variation.

During its five years, the CP<sub>3</sub> on-farm testing project devoted most attention to management and economic aspects of direct seed or no-till annual cropping of spring wheat and barley as alternatives to winter wheat-fallow, and some to winter wheat and potential alternative crops (e.g., oilseeds, triticale). Field tests included comparisons of rates and time of fertilizer application, seeding rates and dates, crop varieties, weed control with pre-plant herbicide in no-till and conventional systems, and no-till drill performance. Tests were also conducted for one year on the effect of seed treatments on emergence and tillering of direct seeded spring barley and wheat. Of particular interest to the growers

was the effect of N and S fertilizer management and crop varieties on the agronomic and economic performance of hard red spring wheat and spring barley in minimum tillage and no-till annual cropping systems.

As indicated in earlier chapters, adverse weather conditions in both 2001 and 2002 from untimely and below normal precipitation, and late spring frosts were extremely detrimental to spring crops. Nevertheless, it is just as important to evaluate performance of these systems under stress conditions as in 'better' years knowing that such cycles will recur in the natural climate of the dryland areas.

### MANAGEMENT OF SPRING WHEAT IN DIRECT SEED AND MINIMUM TILLAGE SYSTEMS

#### HARD RED SPRING WHEAT

In 1999, six on-farm tests (three using minimum tillage and/or three using direct seed) across zones ranging from 7 to 13 inches of average annual precipitation showed that grain yields and protein content, and economic returns from hard red spring wheat (HRSW) were unaffected by time of fertilizer application (late fall, spring or split fall/spring). Moreover, most of the N applied late in the fall could not be accounted for in the spring soil samples, and the bulk of what was accounted for remained in the first foot of soil where later it would be positionally-unavailable for uptake and protein synthesis in grain. Apparently the ammonium N in these treatments did not convert to nitrate in the fall and therefore did not move downward with over-winter precipitation.

Yield potentials were not achieved in most cases and protein levels were below

## CHAPTER 6

the goal of 14% in three of the on-farm tests and was attained only with a rate of 5 lb of available N bu<sup>-1</sup> which is considerably higher than the 3 to 3.2 lb N bu<sup>-1</sup> recommended based on previous research (Esser, 1999). However, in most cases, yield and/or protein increases were large enough to cover the additional N because net returns above N costs were either unaffected or increased with increased N fertilizer rates in the range of 50 to 120 lb ac<sup>-1</sup> of N.

Pan et al. (2001) conducted N fertility research on Shano silt loam soil near Ralston, WA during 1995-2000 that included no-till treatments of continuous HRSW and a HRSW-SB (spring barley) rotations. The N application for HRSW was split with greater than 50% (45 to 80 lb ac<sup>-1</sup>) applied as anhydrous NH<sub>3</sub> in early to mid October with a chisel applicator in 1995-97, and as urea ammonium nitrate point injected with a spoke wheel applicator in 1998-99. The spring barley received all N at planting time in a one-pass sow/fertilize operation with a John Deere 9400 hoe drill (Fig. 4.9). Nitrogen was applied as urea ammonium nitrate banded 2 inches below the seed at rates that ranged from 26 lb ac<sup>-1</sup> in 1996 to 83 lb ac<sup>-1</sup> in 1999.

Grain yields of continuous HRSW ranged from 29 to 50 bu ac<sup>-1</sup> and in rotation with SB from 33 to 50 bu ac<sup>-1</sup>. Grain protein in both systems were similar and exceeded 14% (up to 18%) all years except 1997 when grain yield goals were exceeded. Early fall application of N fertilizer that allowed deeper movement of N over winter is likely responsible for the higher grain protein contents of HRSW in the Pan et al. (2001) experiments compared with those in the on-farm tests where the N was applied in late fall.

Variety selection can affect profitability in HRSW production. A test in a 7 to 10-inch annual precipitation zone showed that the varieties 'Spillman' and 'Scarlet' outyielded 'Kulm' and 'Westbred 926' and produced higher gross economic returns even with a lower protein content. For example, 'Kulm' that yielded 14.9 bu ac<sup>-1</sup> with a 16.1% protein content would require a 19.9% protein content to have the same gross return of \$80 ac<sup>-1</sup> as 'Scarlet' that yielded 19 bu ac<sup>-1</sup> and 15.9% protein (Esser, 1999). This illustrates the point that with economic returns, yield may sometimes override the protein factor (Fig. 6.2).

Field selection and soil sampling are also very important in HRSW production (Fig. 6.3). According to Esser

(1999) soil sampling for residual N may be more economically feasible than applying fall N fertilizer indiscreetly and relying on winter and spring precipitation to move the N far enough into the soil profile where it would be available for uptake and grain protein synthesis.

Fields most favorable for cropping HRSW are those with the highest amounts of residual N in the second and third foot of the soil-root zone and, thus, minimally-dependent if at all on fall fertilization. With higher rates of N applied for HRSW to achieve the desired protein levels, there will likely be higher amounts of residual N remaining after harvest and, thus, through soil sampling the fertilizer rate for recropping could be reduced accordingly. It is also important to know the distribution of residual N in the soil profile and to select the following crop according to its ability to use the nutrient most efficiently.

Little appears known about the relationship between sulfur application and protein management for HRSW in the dryland areas. An on-farm test in a 11 to 12-inch annual precipitation zone showed that there was no significant difference in grain yield, protein content, or seed quality of HRSW with application of 10, 15, or 20 lb

ac<sup>-1</sup> of S though there was a trend for higher yield and protein content with increased S rates. Gross returns and net returns above S cost were unaffected by S application. In this test N and P were applied at rates of 55 and 15 lb ac<sup>-1</sup>, respectively.

In 2000, on-farm tests of HRSW production using direct seed methods were conducted on five farms in Lincoln and Adams Counties where annual precipitation ranged from 8 to 13 inches (Esser, 2000). One trend was increased grain protein content with higher soil test values of N in the year prior to sowing. This suggests a benefit from applying N in the fall while temperatures are favorable for nitrification and soil tests indicate a N deficiency in the root zone. Early fall fertilization also reduces the amount of N that otherwise would need to be applied in the spring. High N rates needed for HRSW, if improperly applied in the spring, can reduce germination and injure seedlings of wheat and barley plants. Another trend indicated by the on-farm tests was increased grain protein content with increasing N content of plant tissue.

Other results supported those for 1999 (Esser, 2000). Increased N fertilizer application as high as 5 lb available N bu<sup>-1</sup> of wheat did not ensure



FIGURE 6.2. On-farm test of direct seeded hard red spring wheat varieties on the Ross Heimbigner farm in a 10-12 inch annual precipitation area in Adams County. Variety selection for increased yield and protein content can affect profitability in hard red spring wheat production. Tests showed that with net returns, grain yield may override the protein factor. Photograph by A. Esser, WSU Cooperative Extension.

a protein content of 14% or more. However, the on-farm tests showed, as in the prior year, that additional investments in N fertilizer were most always recovered and provided additional economic returns because of increased grain yields and/or protein content. The studies cautioned that high rates of N associated with HRSW production may pose potential environmental concerns, i.e., from N leaching or runoff. However, results indicate that with proper management, most of the additional fertilizer was utilized by the succeeding crop with the balance remaining as residual N in the top two feet of the soil profile (Esser, 2000).

A test of three HRSW varieties, 'Jefferson', 'McNeal', and 'Scarlet', conducted in a 10 to 12-inch annual precipitation zone using minimum tillage showed that although slight protein differences were detected, yields were similar at 31 bu ac<sup>-1</sup>. However the gross revenue for the three varieties was the same at \$67.44 ac<sup>-1</sup> since all of the varieties received the same discount of \$1.02 bu<sup>-1</sup> for protein content (Esser, 2000).

Severe frost, early heat stress and drought in 2001 limited results of tests

with HRSW conducted on four farms evaluating varietal performance, timing of N fertilizer application, and N and S requirements for profitable production in minimum tillage or direct seed systems (Esser, 2001). In 2002, tests on two farms showed that an additional 10 lb ac<sup>-1</sup> of N fertilizer as a solution of urea, ammonium nitrate and sulfur (solution 32) applied as a top-dress to HRSW simultaneously with a broadleaf weed herbicide approximately one month after sowing did not significantly increase plant tissue N or S at wheat boot stage (10 on the Feekes scale) compared with herbicide only at either location. Grain yields and protein content of wheat were unaffected by treatment (average 8 bu ac<sup>-1</sup> and 16.4% protein) but fertilizer application did increase grain test weight slightly on one farm. Yields and protein were not measured on the second farm because of poor growing conditions (Esser and Veseth, 2002).

#### SOFT WHITE SPRING WHEAT

In 2002 an on-farm test was conducted six mi south of Ritzville, WA in a 11 to 12-inch annual precipitation zone where 'Wawawi' soft white spring wheat was sown at 70 lb ac<sup>-1</sup> with a

low-disturbance McGregor direct seed drill which simultaneously applied N-P-K-S fertilizer at three rates: 50-5-0-10, 75-5-0-15, and 100-5-0-20 (Esser, 2002). The increased N and S application rates had no effect on stand establishment, tillers per plant, grain yield or test weight, but significantly increased grain protein content from 13.5% at the lowest rate to 13.9% at the highest rate. Economic returns above fertilizer costs were greatest with the lowest rate of fertilizer application at \$63 ac<sup>-1</sup> compared with \$57 and \$48 for the middle and highest rates, respectively.

In another on-farm test with soft white spring wheat for the 2002 crop season conducted in Lincoln County in a 10 to 12-inch annual precipitation zone, comparisons were made between 1) fall fertilizer applied with a low disturbance applicator, 2) spring fertilizer applied with a low disturbance applicator, 3) spring fertilizer dribbled on the surface with a low disturbance applicator, and 4) spring fertilizer applied and wheat direct seeded with a high disturbance shop-built drill. There were no significant differences among treatments in grain yield, test weight and protein content although grain yield of the spring fertilizer/direct seed treatment trended lower than the rest at 18 bu ac<sup>-1</sup> compared with the average of all treatments at 21.7 bu ac<sup>-1</sup>. Overall, the trial produced good seed quality with test weight and protein content at 61.1 lb bu<sup>-1</sup> and 11.3%, respectively (Esser, 2002).

An on-farm trial was conducted five mi northwest of Wilbur, WA in Lincoln County (14-inch annual precipitation zone) in the 2002 season which compared 'Zak', a newly released variety from WSU, with 'Alpowa' as to their adaptation and performance under direct seed conditions. Both varieties were sown at 65 lb ac<sup>-1</sup> with a Concord™ high disturbance direct seed drill using 12-inch paired row spacing. There were no significant differences between the two varieties in plant population, tillers per plant, and test weight (average 58.8 lb bu<sup>-1</sup>). However, 'Alpowa' produced the highest yield at 28.3 bu ac<sup>-1</sup> and a more favorable grain protein content at 13.1% compared with 'Zak' at 25.7 bu ac<sup>-1</sup> yield and 13.5% protein. In addition, 'Alpowa' produced the highest gross economic return at \$122.04 ac<sup>-1</sup>, or about \$10 ac<sup>-1</sup> more than 'Zak'.

#### HARD WHITE SPRING WHEAT

An on-farm experiment similar to that for soft white spring wheat was conducted to evaluate the effects of



**FIGURE 6.3.** Fall soil sampling for a direct seed, hard red spring wheat on-farm test. Nitrogen management to meet desired yield and protein levels is very important in successful production of hard red spring wheat. Grain protein content is generally increased with higher test values in the fall prior to the crop year from either applied fertilizer or residual soil nitrogen. With low residual N it is especially important to apply N fertilizer early in the prior fall (no later than early to mid October) to ensure high grain protein content of the spring crop. On-farm testing has shown that investments in nitrogen fertilizer for hard red spring wheat were almost always recovered and increased economic returns through increased grain yields and/or protein content. Photograph by A. Esser, WSU Extension.

## CHAPTER 6

fall versus spring fertilization on the agronomic performance of hard white spring wheat in a reduced tillage system (Esser, 2002). Comparisons were made between 1) fall fertilizer applied with a low-disturbance applicator, 2) spring fertilizer applied with a low-disturbance applicator, 3) spring fertilizer dribbled with a low-disturbance applicator, and 4) spring fertilizer applied with a high-disturbance shank applicator.

There were no significant differences in plant population among the four treatments with an average of 13.9 plants  $\text{ft}^{-2}$ . Fall fertilizer/low-disturbance soil treatment grain yield was 28.7  $\text{bu ac}^{-1}$  and significantly higher than yields of 26.9 and 26.8  $\text{bu ac}^{-1}$  from the spring fertilizer dribbled, and spring fertilized/low-disturbance treatments, respectively, but not the 27.7  $\text{bu ac}^{-1}$  yield obtained from spring fertilizer applied with the high-disturbance shank applicator. Moreover, the grain yield of this latter treatment was not significantly different than the spring fertilizer/dribbled and spring fertilizer/low-disturbance treatments.

The spring fertilizer/high-disturbance grain protein content of 14.6% and test weight of 56.4  $\text{lb bu}^{-1}$  were significantly different than the spring fertilizer/dribbled treatment with a protein content of 12.9% and test weight of 59.5  $\text{lb bu}^{-1}$ . The values of these parameters for the two remaining treatments were between and not significantly different from these highs and lows. Analysis of soil samples taken at one-foot increments to a depth of six ft prior to spring fertilization showed that all 65 lb of the fall-applied N was present in the top foot of soil and that there was no significant increase of N in the layers below compared with a no fall fertilizer check treatment.

### ECONOMIC COMPARISON OF HARD RED SPRING WHEAT (HRSW) WITH SOFT WHITE SPRING WHEAT (SWSW)

Economic evaluations of the on-farm tests in minimum tillage and direct seed systems generally indicate that the net returns over fertilizer, or fertilizer plus seed and interest costs, are significantly greater for SWSW compared with HRSW. This is mainly because of higher yields usually obtained with SWSW but in others because of higher N costs with HRSW (Esser, 1999). For example, on-farm tests comparing fall, spring, and split

fall/spring fertilizer applications on two farms in a 8 to 10-inch precipitation zone in Adams County, WA in 1999, showed net returns for SWSW were \$5.53 to \$13.36 greater on one farm and \$22.87 to \$32.91 on another than for three HRSW treatments (Table 6.1).

However, in some situations the economics may be different. Table 6.2 shows that in an on-farm test in Lincoln County in 1999 it required about 1, 4, and 7 more  $\text{bu ac}^{-1}$  of SWSW fertilized at a rate of 60  $\text{lb N ac}^{-1}$  to equal the economic returns from HRSW fertilized with 60, 90, and 120  $\text{lb N ac}^{-1}$  respectively. The highest N rate at 120  $\text{lb ac}^{-1}$  with HRSW, the only one that made 14% protein wheat, was the most profitable treatment.

Data from a WSU variety testing program (<http://variety.wsu.edu>) showed that the 1997-1999 average yield of four commercial SWSW and HRSW varieties grown at three locations in a 11 to 15-inch precipitation zone according to WSU fertilizer recommendations were 56.2 and 49.0  $\text{bu ac}^{-1}$ , respectively. The difference of 7.2  $\text{bu ac}^{-1}$  in favor of the SWSW, as in the Lincoln County on-farm test with the 120  $\text{lb ac}^{-1}$  rate of N fertilizer, would on an economic basis make the two classes in this case about even. Tests

in the 7 to 14-inch precipitation zone show the yield of SWSW about 4  $\text{bu ac}^{-1}$  higher than HRSW, and thus the two classes could be economically equivalent at a lower N rate (Esser, 1999).

### AGRONOMIC AND ECONOMIC COMPARISONS OF DIRECT SEED AND CONVENTIONAL PLANTED SPRING BARLEY

On-farm tests conducted in Adams (one test, average annual precipitation 11 to 12 inches) and northern Lincoln (three tests, average annual precipitation 12 to 14 inches) Counties in 1998 showed that plant populations, tillers per plant, and wild oat (*Avena fatua*) plant populations when present, were generally comparable for the two systems (Esser, 1998; Esser, 2000; Fig 6.4). However, barley grain yields were significantly higher with the conventional system in three of the four farms although the differences were relatively small (1.33 vs 1.17  $\text{t ac}^{-1}$  in Adams County, and 0.59 vs 0.56  $\text{t ac}^{-1}$  on one farm that suffered hail damage and 1.93 vs 1.73  $\text{t ac}^{-1}$  on a second farm in Lincoln County). In the Adams County on-farm test, the gross return from the higher yielding conventional system was about



FIGURE 6.4. Harvesting the final year of a 3-yr on-farm test comparing direct seeded vs conventional seeded spring barley at the R&R Farms in a 14-inch annual precipitation area in northern Lincoln County. Yield is measured with weight pads. The main economic advantage with direct seeding over the conventional practice was time saved in field operations. Previous years herbicide application for wild oat control increased barley yields to a greater extent than the difference between yields from the conventional and direct seed systems. Photograph by A. Esser, WSU Cooperative Extension.

\$11 ac<sup>-1</sup> higher than from no-till, but because the crop establishment cost was less with no-till the net return for the conventional system was only about \$5 ac<sup>-1</sup> more than that for no-till. On two farms in Lincoln County barley yields were highest with the conventional system that also produced both the highest gross returns (\$3.15 and \$12.80 ac<sup>-1</sup> more than no-till) and returns after establishment costs [\$5.87 and \$17.38 ac<sup>-1</sup> (for comparable rates of N fertilizer) more than no-till]. On the third farm there was no difference in grain yields between the two systems and with gross returns being equal, the net return after crop establishment costs was \$12.85 ac<sup>-1</sup> in favor of the conventional system.

In these experiments both treatments were sown on the same day or within two days of each other. According to Esser (1998) the sowing date for the no-till treatment probably should have been at least a week earlier than the conventional treatment which would likely have improved the yield potential of the no-till spring barley. Another factor not included in the economic analysis is the time required for field operations with the two systems. The conventional operations averaged over the four farms required 1.86 more time than that for no-till (Esser, 1998). The time saved with no-till could be applied to custom work for additional income that would further offset the costs with this practice. Costs with no-

till on two of the Lincoln County farms could also have been reduced by eliminating the multiple harrowing operations done to level the soil surface after subsoiling and to stimulate wild oat germination (Esser, 1998).

Comparisons between agronomic and economic performance of conventional and no-till (used direct seed designation in 1999) spring barley were continued in 1999 and 2000 on one farm in northern Lincoln County with emphasis on wild oat control with triallate herbicide (Esser, 1999, 2000). The farm was the previous year's site for comparing conventional spring seeded barley with no-till barley fertilized with 76 or 96 lb ac<sup>-1</sup> of N. Triallate herbicide applied in 1999 only on the direct seed system did not significantly reduce wild oat populations compared with no herbicide, but did reduce tillering and increased the direct seed barley yield by 0.47 t ac<sup>-1</sup> making it comparable with conventional seeding without wild oat control.

Other agronomic comparisons between direct seed and conventionally-sown barley were similar to those of 1998. Economic comparisons for the two systems were similar to the 1998 trial results; the direct seed system had higher input and operating costs associated with broad-spectrum herbicide application and equipment rental whereas the conventional system had higher ownership costs associated with tillage equipment.

In 2000, the on-farm test was imposed on the same site used for triallate herbicide comparisons in 1999, and for comparing N application rates in 1998, while maintaining the integrity of the conventional and no-till treatments. The three new treatments were: 1) conventional (no triallate in 1999 and 76 lb ac<sup>-1</sup> of N in 1998); 2) no-till (with triallate in 1999 and 76 lb ac<sup>-1</sup> of N in 1998); and 3) no-till (no triallate in 1999 and 96 lb ac<sup>-1</sup> of N in 1998). All three treatments received 76 lb ac<sup>-1</sup> of N for the 2000 crop year and the recommended rate of triallate incorporated in the soil.

Plant populations and tillering of 'Baronesse' barley were similar for all treatments. The previous two years of treatments, increased fertilizer in 1998, and herbicide application for wild oat control in 1999, had a greater impact on barley yields and economics than the conventional versus no-till comparisons. The grain yield of 1.40 t ac<sup>-1</sup> from no-till treated with triallate in 1999 was significantly higher than the conventional and no-till yields of

**Table 6.1. On-farm test comparison of grain yield, protein content and net returns of three treatments of direct seeded hard red spring wheat (HRSW) with one treatment of direct seeded soft white spring wheat (SWSW) on two farms in Adams County, WA in 1999<sup>1</sup>.**

Farm 1					
Treatment	F/S <sup>2</sup>	Yield	Protein content	Net return	Gain in NR <sup>3</sup> with SWSW
	(lb N ac <sup>-1</sup> )	(bu ac <sup>-1</sup> )	(%)	(\$ ac <sup>-1</sup> )	(\$ ac <sup>-1</sup> )
HRSW-1	74/23	20.2b <sup>4</sup>	13.1b	30.63c	12.45
HRSW-2	45/52	20.7b	13.6a	37.55b	5.53
HRSW-3	0/97	19.0c	13.2b	29.72c	13.36
SWSW	0/63	22.6a	10.5c	43.08a	—
LSD <sub>(0.05)</sub>	—	0.9	0.2	2.64	—
CV (%)	—	2.1	0.9	3.5	—
Farm 2					
HRSW-1	42/10	30.3	10.6b	39.42c	32.91
HRSW-2	42/40	31.5	11.1b	42.04bc	30.24
HRSW-3	42/70	33.5	12.0a	49.46b	22.87
SWSW	42/10	32.5	9.2c	72.33a	—
LSD <sub>(0.05)</sub>	—	NS <sup>5</sup>	—	8.32	—
CV (%)	—	4.9	—	7.7	—

<sup>1</sup>Source: Esser (1999).

<sup>2</sup>F = lb ac<sup>-1</sup> fall-applied N fertilizer; S = lb ac<sup>-1</sup> spring-applied N fertilizer.

<sup>3</sup>NR = net return.

<sup>4</sup>Numbers in a column followed by the same letter are not significantly different at P<0.05.

<sup>5</sup>Not significant.

**Table 6.2. Estimated soft white spring wheat (SWSW) yields needed to equal net returns above seed and N fertilizer costs from three hard red spring wheat (HRSW) treatments in an on-farm test in northern Lincoln County, WA in 1999<sup>1</sup>.**

Treatment (lb N ac <sup>-1</sup> )	HRSW yield (bu ac <sup>-1</sup> )	Return above costs (\$ ac <sup>-1</sup> )	SWSW Yield <sup>2</sup> (bu ac <sup>-1</sup> )
60	39.6	95.39	40.5
90	41.2	110.47	45.7
120 <sup>3</sup>	42.1	119.87	49.0

<sup>1</sup>Source: Esser (1999).

<sup>2</sup>Assumes a SWSW seed cost of \$9.50 ac<sup>-1</sup> and a selling price of \$2.89 bu<sup>-1</sup>, the FOB price at Ritzville, WA, on September 15, 1999. It also assumes an N rate of 60 lb N ac<sup>-1</sup> applied for SWSW and equal sowing rates for both wheat classes.

<sup>3</sup>The only treatment with greater than 14% protein content.

1.32 and 1.25 t ac<sup>-1</sup>, respectively, that had no wild oat control the previous year. Gross returns of \$99.18 ac<sup>-1</sup> and returns above crop establishment costs of \$22.03 ac<sup>-1</sup> were highest for the no-till treated with triallate in 1999. This compares with gross returns of \$93.46 and \$88.58 ac<sup>-1</sup>, and returns above crop establishment costs of \$20.30 and \$11.43 ac<sup>-1</sup> for the conventional and no-till treatments, respectively, with no wild oat control in 1999.

### EFFECT OF INCREASED SEEDING RATES AND SEED TREATMENTS ON GRAIN YIELD AND ECONOMICS OF DIRECT SEED (NO-TILL) SPRING WHEAT AND BARLEY

On-farm tests conducted on one farm in northern Lincoln County in a 12 to 14-inch average annual precipitation zone during 1999-2001 showed that increasing the sowing rate of 'Baroness' spring barley from 70 lb ac<sup>-1</sup> to 90 lb ac<sup>-1</sup> improved stand populations but did not affect grain yields in two years out of three. In 2000 the highest sowing rate of 90 lb ac<sup>-1</sup> resulted in a yield loss of 0.05 t ac<sup>-1</sup> (1.86 versus 1.81 t ac<sup>-1</sup>, significant at P < 0.10) as compared with the lowest rate of 70 lb ac<sup>-1</sup> (Esser, 1999, 2000, 2001). Similarly, gross returns and returns above seed costs were unaffected by sowing rate in two years out of three, but reduced by the highest sowing rate in one year.

In another test on the same farm in 2000 and 2001, stand establishment and grain yields of direct seeded 'Alpowa' spring wheat and economic returns were unaffected by increasing the sowing rate from 60 to 80 lb ac<sup>-1</sup>. In all tests sowing was with a Conserva Pak® direct seed hoe-type drill with 12-inch row spacing.

Esser (2002) concluded that over three years of testing on the aforementioned Lincoln County farm there were no differences in emergence one month after sowing and in grain test weight of 'Alpowa' soft white spring wheat sown at 60, 70, and 80 lb ac<sup>-1</sup>. The average grain yield of 29.7 bu ac<sup>-1</sup> from sowing 70 lb of seed ac<sup>-1</sup> was significantly higher than the average yield of 28.8 bu ac<sup>-1</sup> resulting from sowing 80 lb of seed ac<sup>-1</sup>. The study showed that the gross economic return averaged \$91.17 and \$88.81 ac<sup>-1</sup> for sowing rates of 70 and 80 lb ac<sup>-1</sup>, respectively. Economic return above seed costs were \$85.34 and \$82.14 ac<sup>-1</sup> for these sowing rates in the same

order. Esser (2002) calculates that for the rotation used over the three years of the study on this farm, the lower sowing rate had a cost savings of \$840 yr<sup>-1</sup> and a 3.1% increase in yield for an additional gross of \$2,500 yr<sup>-1</sup>. Consequently, there was an increase in profitability on this farm of \$3,340 yr<sup>-1</sup> (Esser and Veseth, 2002).

### EFFECT OF SEED TREATMENTS ON SPRING BARLEY AND WHEAT

Research has shown that seed treatment can be an economical practice for improving stand establishment of cereals in direct seed systems. On-farm tests conducted in 2000 showed that treating seed with labeled rates of Maxim/Apron XL, Raxil, and Dividend XL did not affect plant populations, plant tillering or grain yields of direct seeded spring barley in Adams County (11-inch average annual precipitation zone), or of 'Alpowa' spring wheat in northern Lincoln County (12-inch average annual precipitation zone). Barley was sown with a John Deere 750 low-disturbance direct seed drill on a 7.5-in row spacing, and wheat with a Flexi-coil 820 direct seed air drill equipped with modified Anderson™ openers on a 9-inch row spacing (Esser, 2000).

A trial in 2002 conducted 14 mi northeast of Ritzville in Adams County compared the effect of starter fertil-

izer with SEEDLIFE™, a seed treatment sometimes applied for spring wheat production. The treatments were starter fertilizer (16 lb N, 6 lb P, 1 lb K plus a trace of Zn per acre), SEEDLIFE at labeled rates, starter fertilizer plus SEEDLIFE, and a check with no amendments (Esser and Veseth, 2002). The test crop was a blend of the soft white varieties 'Edwall' and 'Zak' sown at 85 lb ac<sup>-1</sup> with a double disk drill. There was no difference in stand establishment among the four treatments with an average of 15 plants ft<sup>-2</sup>. The combined starter fertilizer-SEEDLIFE treatment produced the highest yield at 20.0 bu ac<sup>-1</sup>. The yield from SEEDLIFE only at 17.9 bu ac<sup>-1</sup> was significantly higher than from starter fertilizer only at 16.3 bu ac<sup>-1</sup>. However check yield of 17.8 bu ac<sup>-1</sup> was not significantly different from the SEEDLIFE or starter fertilizer only treatments (Esser, 2002).

During 1998-2002 Esser and Veseth conducted over 60 on-farm tests covering a wide scope of work that is impossible to present in detail in this chapter. Table 6.3 summarizes the individual tests by research topic and makes it easy to trace a specific topic of interest to the annual report where it is published in its original form. The annual reports are available from most WSU Extension offices in the area.



FIGURE 6.5. Applying fall fertilizer for hard red spring wheat production using a conservation two-pass seeding system in an on-farm test at Jim Melville's farm (see Fig. 6.1). The on-farm testing and extension education programs have worked extensively with dryland growers in adapting direct seed systems for profitable production and erosion control on their farms. As a result the Melville farm has transitioned almost entirely from a conventional into a direct seed (minimum-or no-till) system of crop production in a 10 to 12 inch precipitation zone. Photograph by A. Esser, WSU Cooperative Extension.

## EXTENSION EDUCATION IN WIND EROSION AND AIR QUALITY CONTROL

Technology transfer programs and informational products working in concert with research have made significant contributions towards the goal of achieving wind erosion and air quality control on Columbia Plateau farmlands. Under the leadership of R.J. Veseth, Conservation Tillage Specialist serving extension programs both at Washington State University and the University of Idaho, the major thrust has been to enhance grower adoption of wind erosion control practices through accelerated development and testing of new research technologies and growers' access to them.

The CP<sub>3</sub> extension education effort has worked closely with other university specialists to summarize and make available to growers new "state-of-the-art" conservation tillage management technologies based on an integrated cropping systems approach (Veseth, 2001). This information assists growers in: 1) fitting or matching new conservation technologies to specific agrometeorological zones, 2) adapting new technologies to their farming systems, and 3) integrating the new technologies with other components of the management system (Fig. 6.5).

The CP<sub>3</sub> extension education is part of a broader conservation tillage program that includes the research and education goals of STEEP (Solutions to Environmental and Economic Problems) program on conservation farming (primarily dedicated to controlling water erosion) across a three-state region (Idaho, Oregon, and Washington). Because the approaches in technology transfer to control wind or water erosion are in most cases very similar, their mix in the education program has been an asset to the development and implementation of conservation farming by growers. The following summarizes the approaches currently being used to develop and distribute information to a broad audience on the latest developments in research related to wind erosion and air quality control (Veseth, 1999, 2000, 2001, 2002).

### PUBLICATIONS

The core publications are the *Pacific Northwest (PNW) Conservation Tillage Handbook* and the *PNW Conservation Tillage Update*. These incorporate virtually all of the educational materials on conservation tillage that are products of the STEEP and CP<sub>3</sub> programs. The *Handbook* is a three-ring binder publi-

cation that is updated with the new and revised *PNW Handbook Series* that are normally distributed through the *Update* for addition to the *Handbook*.

The *Handbook Series* articles are a continuum in the summarization of the latest developments and technologies from conservation tillage research and field-testing with emphasis on adaptation of new findings by growers on their farms. The *Update* (Fig. 6.6) is a popular newsletter published two or three times a year that highlights: 1) the latest in CP<sub>3</sub> research, 2) program announcements on the upcoming annual PNW Direct Seed Cropping Systems Conference, 3) availability of Conference Proceedings and videotapes, 4) Web Site Resources for Direct Seed Systems, and 5) listing of upcoming field days, tours and conferences relating to

direct seed cropping systems as well as information on other educational resources and coming events. Subscribers to the *Update* include producers (~2000), county extension agents, conservation districts, USDA-NRCS staff, agricultural service industry, agricultural media and other support personnel (~800 non producers).

The updated *PNW Conservation Tillage Handbook* and individual copies of the *Handbook Series* are accessible on the Internet home page (<http://pnwsteep.wsu.edu>) along with recent issues of the *Conservation Tillage Update*, listings of other conservation tillage information resources, and forthcoming relevant events. A list of publications pertinent to CP<sub>3</sub> is available at <http://pnw-winderosion.wsu.edu/>.

**Pacific Northwest STEEP Extension**

# Conservation Tillage Update



**University of Idaho**

**Oregon State University**

**Washington State University**

**May 2002**

---

SPECIAL ISSUE TOPICS

- **2002 Northwest Field Days, Tours and Demonstrations – Featuring Direct Seed Cropping Systems Technologies** - (Page 2)
- **January 2002 NW Direct Seed Cropping Systems Conference Proceedings & Highlights** -- (Page 7)
- **Expanding Internet / E-mail Access to PNW Direct Seed Cropping Systems Technology** --- Pacific Northwest Conservation Tillage Handbook Series No. 17, Chap. 10 -- (Page 9)
- **Occurrence of the Rhizoctonia "Bare Patch" Disease in Diverse Direct-Seed Spring Cropping Systems in a Low-Precipitation Zone** - Pacific Northwest Conservation Tillage Handbook Series No. 19, Chap. 4 -- (Page 13)
- **Updated Table of Contents --- Pacific Northwest Conservation Tillage Handbook** -- (Page 23)
- **Erratum -- Replacement of page 5 in PNW Conservation Tillage Handbook Series No. 16 (Chap. 10) – "Economics of Conservation Tillage in a Wheat-Fallow Rotation," included in the Feb. 2002 issue of this Update** -- (Page 27)
- **2002-2003 Coming Events – Cropping Systems Technologies for Direct Seeding** --- (Page 29 and Back Cover)

**Make Plans to Attend!!!**

**6th Annual**

**Northwest**

**DIRECT SEED**

**CROPPING**

**SYSTEMS**



**Conference**

**and Trade Show!!!**

**January 8-10, 2003**

**WestCoast Hotel, Pasco, WA**

(Formerly the Doubletree)

....Featuring over 28 speakers, including 7 growers, from Idaho, Oregon, Washington, South Dakota and New Zealand.

FIGURE 6.6. *The Conservation Tillage Update* is a popular newsletter that highlights the latest in research, educational resources, and upcoming events on conservation farming in the inland Northwest region. Source: R.J. Veseth, WSU and U of I.

**INTERNET ACCESS**

The Internet Web site <http://pnwsteepp.wsu.edu> entitled *PNW STEEP Conservation Tillage Systems Technology Source* was initiated in 1997 under the STEEP program but includes a full complement of educational activities and conservation tillage information applicable to wind erosion control. The site includes the entire *PNW Conservation Tillage Handbook Series*, *PNW STEEP III Extension Conservation Tillage Update* newsletters since 1996, Proceedings of the Northwest Direct Seed Cropping Systems Conferences, Annual STEEP Research Reports, PNW STEEP On-farm Test Results publications, PNW Direct Seed Case Study publications and other related conservation tillage information resources. A search engine provides additional keyword searches within the Web Site. The Site also includes a calendar of events on direct seed systems that is continually updated with current listings of forthcoming activities promoting this technology. A complete

list of refereed journal articles with abstracts, conference proceedings and published abstracts for the CP<sub>3</sub> is available on the CP<sub>3</sub> Web site (<http://pnw-winderosion.wsu.edu>).

Since 1999, the Internet access additionally has provided a Pacific Northwest e-mail/Internet List Server that allows subscribers to communicate, seek and exchange information on issues, questions, and experiences with direct seed systems. Messages are received by e-mail and stored on the server Internet Site for current use and for later access by new subscribers. For example, a producer may observe what appears to be the presence of a new or unusual pest in his/her no-till or minimum till seeded crop and seeks an explanation and solution for what might develop into a potential problem.

Other problems or questions may be related to the operation of no-till or minimum till equipment, herbicide performance, or unusual crop growth behavior in the field. Entering the observation and questions by e-mail

on the List Server enables the producer to quickly screen a broad audience of growers, extension and agency specialists, researchers, and agricultural industry field staff for answers from individuals who may have the knowledge being sought or might have experienced a similar situation in another area.

**CONFERENCES, CONSERVATION FIELD DAYS AND TOURS**

A highlight of the educational program is the regional *Annual Northwest Direct Seed Cropping Systems Conference* conducted in early to mid January as a service to Northwest growers. The *Conference* is organized by the PNW STEEP program and the PNW Direct Seed Association formed in 2000 under the leadership of regional wheat and barley growers. Sponsors include agricultural industry services, agribusinesses, grower organizations and agricultural support groups and agencies. The two-day event now in its sixth year draws a registered attendance of 600 to 900 including a significant number of individuals and groups from outside the region. The program generally features 20 to 30 speakers including researchers, industry and agency representatives, and growers across the region as well as national and international experts on conservation farming. In-depth sessions on direct seeding include topics such as: residue management, benefits to soil quality, drills and equipment, soil fertility, crop selection and rotations, pest management, and farm economics. In addition to the speaker sessions, a *Direct Seed Research and Educational Poster Exhibition* is available throughout the *Conference* for viewing poster presentations on research relevant to direct seed systems in the Pacific Northwest and outside the region.

Based on attendance numbers and respondent evaluations, the *Annual Conference* has been a major success in terms of its overall goal of promoting the adaptation of direct seed cropping systems in the inland Northwest and has the highest attendance of any agricultural conference in the Pacific Northwest. Unquestionably, the major benefit originates from the opportunity for a broad-scale grower-to-grower exchange of information, ideas and experiences with conservation tillage over a range of soils, climatic conditions and cropping systems. The growers' observations are supplemented by research input explaining cause and effect relationships among agronomic variables and analyzing the profitability of conservation farming systems.

**Table 6.3. Summary of on-farm tests by research topic and treatment during 1998-2002<sup>1, 2</sup>.**

Research interest	Treatment	No. of trials	Year conducted
<b>Hard red spring wheat</b>	N fertilization	11	1999, 2000, 2001, 2002 <sup>3</sup>
	S fertilization	2	1999, 2001
	Variety testing	3	1999, 2000, 2001
<b>Soft white spring wheat</b>	N fertilization	1	1998
	Variety testing	1	2002
<b>Spring wheat (general)</b>	Sowing rates	3	2000, 2001, 2002
	Classes	1	2000
	Seed treatment	1	2002
	N fertilization	1	2002
<b>Spring barley</b>	Sowing rates	4	1999, 2000, 2001
	Fertilization	4	1998, 1999, 2000, 2001
	No-till/tillage	5	1998, 2000
	Seed treatment	2	2000
	Variety testing	2	2001, 2002
	Weed control	2	2000, 2001
<b>Hard white spring wheat</b>	N fertilization	1	1999
<b>Spring cereals (general)</b>	Fertilization	4	2001, 2002
	Type comparisons	1	2002
<b>Winter wheat</b>	Drill/variety	1	2001
	Recrop	1	2002
<b>Chemical fallow</b>	Fertilization	1	2002
	Herbicide evaluation	1	2002
<b>Oilseeds</b>	Rotations	2	1998, 2002
	Fertilization	5	1998, 1999, 2002
<b>Direct-seed drills</b>	Comparisons	1	2000
<b>Fall sub-soiling</b>	In direct seed	1	2000
	In established wheat	1	2000

<sup>1</sup>Throughout, the on-farm testing program focused on no-till/direct-seed methods and where conventional tillage methods were involved they were a comparison treatment.

<sup>2</sup>The bulk of the tests were conducted in Adams and Lincoln Counties.

<sup>3</sup>The work is reported in the referenced annual reports by A.D. Esser listed at the end of this chapter.

There is a Web Site for the *Direct Seed Cropping Systems Conference* for selecting the 1998 through 2003 conferences for program information. The conference page has a direct access Web Site (<http://pnwsteeep.wsu.edu/directseed>) that is used to publicize the Conferences and provide access later to the proceedings and video information (Veseth, 2002). The page also provides advance information on the objectives and upcoming Conference agenda, brochures, sponsorship prospectus, registration information, poster exhibition registration, hotel registration and the Spokane Ag Expo Web Site.

The CP<sub>3</sub> holds an annual technical review each year, usually for two days in December, at either Spokane, or the Tri-Cities, Washington that is open to the public but especially for persons interested in farmland wind erosion and urban air quality. Objectives, methods and interim results are reported as a series of presentations, and in a proceedings available at the meeting. The review allows opportunity for agency managers and CP<sub>3</sub> scientists to interact with attendees from the region and other states.

The educational program includes agendas for field days, tours and current on-farm trials that feature cropping systems, crop selection, and tillage and seeding methods adaptable for conservation farming (Fig. 6.7). The events are advertised and promoted through the *PNW Conservation Tillage Update* newsletter, Web site, and *PNW Direct Seed List Server*, and regional newspapers.

### SUMMARY OBSERVATIONS

An on-farm testing program was implemented to accelerate the development and adaptation of minimum tillage and no-till (direct seed) systems and more intensive crop rotations that improve farm profitability, erosion control, and soil productivity in low and intermediate precipitation areas of eastern Washington. The main thrust of the work was to evaluate the potential of annual direct-seed cropping of spring cereals in lieu of conventional winter wheat-fallow in the dry areas. On-farm testing has the advantage over traditional long-term field research by responding to the growers' need for more immediate information on agronomic and economic impacts of implementing new crop or soil management systems to address changes in farm policy, environmental concerns and economic conditions.

Studies on the economic feasibility of direct seeded hard red spring wheat (HRSW) showed that increased N fertilizer as high as 5.0 lb of available N bu<sup>-1</sup>, which is considerably higher than the 3.6 lb N bu<sup>-1</sup> recommended based on earlier research, did not guarantee grain protein contents of 14% or higher. However late fall application of N fertilizer with little downward movement over winter may have accounted for low grain protein contents because the N was positionally unavailable at the time of anthesis and grain filling.

Other related research shows that protein contents above 14% for hard red spring wheat were nearly always achieved when ammonium N fertilizer was applied early in the prior fall in time for some nitrification before winter. Nevertheless, on-farm testing showed that investments in higher rates of N fertilizer required for hard red spring wheat were almost always recovered and provided additional returns in terms of increased yield and grain protein, and residual for the succeeding crop.

Variety selection is very important in the profitability of HRSW production. Generally, a variety with greater yield potential and good protein content is likely to be more profitable

than one with lower yield potential but high protein content.

On-farm tests in minimum tillage and direct seed systems showed that in most cases the net returns over fertilizer, or fertilizer plus seed and interest costs, are significantly greater for soft white spring wheat (SWSW) compared with HRSW. This is mostly due to higher yields with SWSW that more than offsets the lower yields and higher fertilizer costs to increase grain protein content with HRSW production. Selecting varieties for their yield potential, and using proper seeding rates are important considerations in the profitability of SWSW varieties.

On-farm comparisons with conventionally sown barley (tilled seedbeds) showed that there were larger agronomic and economic differences among direct seed treatments than between direct seed and conventional planting although direct seeding saved time in field operations. Previous years herbicide application for wild oat control increased barley yields to a greater extent than the difference between yields from the conventional and direct seed systems. Increased seeding rates of both spring wheat and barley did not increase grain yields but decreased the seed test weight of barley, and in one test decreased



FIGURE 6.7. Field tours such as the one pictured here, conducted by Roger Veseth, Conservation Tillage Specialist, on aspects of direct seed cropping systems provide an opportunity for growers to interact with scientists, extension specialists, agribusiness representatives, support groups and each other. These tours often feature the results of on-farm direct seeding methods, crop selection and no-till technologies. These and other aspects of conservation farming are addressed by local, regional and national experts for audiences ranging up to several hundred attendees. This activity has been especially valuable to the CP<sub>3</sub> project and has greatly enhanced its productivity and credibility. Source: R.J. Veseth, WSU and U of I.

## CHAPTER 6

the profitability of direct-seed spring wheat.

The CP<sub>3</sub> extension education effort is a part of the Pacific Northwest Tri-state STEEP (Solutions to Environmental and Economic Problems) research and education program with the objective of developing educational materials and programs on conservation tillage and cropping practices to control wind erosion on the Columbia Plateau farmlands. The education effort uses five approaches for disseminating CP<sub>3</sub> research findings, and learning experiences to user clientele. These include 1) an annual Northwest Direct Seed Cropping System Conference, 2) Internet/e-mail access to new technologies, 3) publications, 4) field days, and 5) presentation at grower's meetings.

The core publications are the Pacific Northwest (PNW) Conservation Tillage Handbook, and the PNW Conservation Tillage Update. The Update is a highly effective newsletter that incorporates many of the products of the STEEP and CP<sub>3</sub> programs into the Handbook including information on research progress, educational materials, and listings of upcoming conferences and tours on direct seed systems. The project Web Site has been redesigned and updated with a new Handbook series and Update issues, research reports and conference information and proceedings.

The PNW Direct Seed E-mail List Server grew from an initial network of 230 growers and agricultural support personnel in early 2000 to over 470 in November 2002. The annual attendance at the Northwest Direct Seed Cropping Systems Conference ranged from 600 to 900 people during the past five years. Information dissemination by the CP<sub>3</sub> is also achieved through an annual review where scientists report on the latest developments and progress by the project to attendees interested in farmland wind erosion and urban air quality.

### REFERENCES

1. Esser, A.D. 1998. On-Farm Test Results—Lincoln-Adams Area. Technical Report OFT-98. Cooperative Extension, Washington State University, Pullman.
2. Esser, A.D. 1999. On-Farm Test Results—Lincoln-Adams Area. Technical Report OFT-99. Cooperative Extension, Washington State University, Pullman.
3. Esser, A.D. 2000. On Farm-Test Results—Lincoln-Adams Area. Technical Report OFT-00. Cooperative Extension, Washington State University, Pullman.
4. Esser, A.D. 2001. On-Farm Test Results—Lincoln-Adams Area. Technical Report OFT-01. Cooperative Extension, Washington State University, Pullman.
5. Esser, A.D. 2002. On-Farm Test Results—Lincoln-Adams Area. Technical Report OFT-02. Cooperative Extension, Washington State University, Pullman.
6. Esser, A.D., and R. Veseth. 2002. On-farm testing of cropping systems technology to improve profitability and erosion control in low and intermediate rainfall areas of eastern Washington. 2002 Annual Report. Northwest Columbia Plateau Wind Erosion/Air Quality Project. Agricultural Research Service, US Dept. of Agriculture, and Washington State University, Pullman. p. 42–48.
7. Pan, W.L., F.L. Young, and K.K. Kidwell. 2001. Carbon and nitrogen cycling in direct-seeded spring cereal alternatives to summer fallow. In B. Brown (ed.). Proceedings of the Western Nutrient Management Conference. Vol. 4:202–209.
8. Veseth, R. 1999. Grower technology access and adaptation for profitable farming systems that control wind erosion. 1999 Annual Report. Northwest Columbia Plateau Wind Erosion/Air Quality Project. Agricultural Research Service, US Dept. of Agriculture, and Washington State University, Pullman. p. 47–58.
9. Veseth, R. 2000. Grower technology access and adaptation for profitable farming systems that control wind erosion. 2000 Annual Report. Northwest Columbia Plateau Wind Erosion/Air Quality Project. Agricultural Research Service, US Dept. of Agriculture, and Washington State University, Pullman. p. 79–88.
10. Veseth, R. 2001. Grower technology access and adaptation for profitable farming systems that control wind erosion. 2001 Annual Report. Northwest Columbia Plateau Wind Erosion/Air Quality Project. Agricultural Research Service, US Dept. of Agriculture, and Washington State University, Pullman. p. 72–83.
11. Veseth, R. 2002. Grower technology access and adaptation for profitable farming systems that control wind erosion. 2002 Annual Report. Northwest Columbia Plateau Wind Erosion/Air Quality Project. Agricultural Research Service, US Dept. of Agriculture, and Washington State University, Pullman. p. 80–89.