

Cropping Systems Research to Control Wind Erosion and Dust Emissions on Dryland Farms

AGRICULTURAL OUTLOOK ON THE COLUMBIA PLATEAU

For more than one hundred years some economists have called winter wheat the principal “economic driver” of dryland cropping on the Columbia Plateau. Compared with other cropping systems winter wheat–fallow consistently has produced the greatest profit for growers and been most responsible for the economic viability of agriculture and related industries in the region. Factors contributing to a predominately winter wheat monoculture have been the crop’s unique adaptability to the region’s winter precipitation climate and its productive

soils, improved tillage and sowing technologies, and to a continued international demand for a soft white wheat that could not be supplied elsewhere in the USA or from other countries.

Summer fallow became a traditional practice early on in the drylands to increase soil water storage from an additional season of winter precipitation that would reduce the risk of uneconomic yields or crop failures more common with annual cropping. Intensive tillage was used to control weeds during the non-crop year, and to create a four- to six-inch deep dust mulch to reduce soil water evaporation and conserve water in the seed-zone over the dry summer months.

The residual moisture helped to ensure establishment of early-planted wheat that yielded 30% more than late-planted wheat that relied on fall rains for germination.

Unfortunately, the export market for Pacific Northwest wheat today is not as lucrative as in the past because of increased competition from other countries now capable of producing similar types of wheat. Moreover, the traditional fallow practice is under scrutiny because fallow land is the primary source of fugitive dust that adversely impacts air quality in down-wind areas. Many soil scientists and growers now view tillage-intensive fallow as an unsustainable farming practice in both the short- and long-term because of the loss of irreplaceable top soil and decline in soil organic matter content associated with it. If traditional fallow management continues, loss of these resources can be offset only by increasing costly production inputs.

Nevertheless, the winter wheat–fallow export paradigm will likely persist as a significant “driver” of Columbia Plateau dryland agriculture well into the 21st century or until other economic alternatives are available. Consequently, the CP₃ continues to conduct research on fallow-based production methods that have a potential to reduce wind erosion, and that do not increase economic hardship to growers. Simultaneously, management and cropping system alternatives to tilled winter wheat–fallow agriculture are being pursued.

During the past decade, and the last seven years in particular, both scientists and growers have given considerable attention to the agronomic and economic feasibility of annual cropping with spring cereals and oilseed



FIGURE 4.1. Operations with the V-sweep undercutter for fallow tillage that leave significant amounts of standing stubble are considerably more effective for wind erosion control than those with implements that flatten or partially bury the stubble. This is especially important following low residue crops. The undercutter has 32-inch wide blades spaced 28 inches apart. Photograph by W.F. Schillinger, WSU. See Figure 1B in Appendix B for additional detail.

crops, and winter wheat in minimum- and no-till systems as alternatives to tilled winter wheat–fallow. Crop diversification with these alternatives should allow growers to improve their economic stability as well as their environmental and resource conservation benefits that are vital to achieving a more sustainable agriculture.

CONTROLLING WIND EROSION AND DUST EMISSIONS WITH SOIL COVER AND RANDOM ROUGHNESS

The most effective approach for controlling wind erosion and dust emissions, where direct suspension is the primary mode of erosion, is soil cover in combination with surface roughness, either or both with large clods (greater than 0.5 inch (13 mm) diameter in the coarse range) and small aggregates (greater than 2-mm diameter in the fine range). Clods not only reduce wind speed at the soil surface, but also like smaller aggregates, reduce the amount of PM available for suspension. The primary source of cover is residues of the previous crop, and if present, these can be supplemented with weed residues such as Russian thistle (Schillinger et al., 1999b). Most information on the effect of crop residue for erosion control has been obtained with cereals, while considerably less is known about soil cover relationships with residues of alterna-

tive crops. Living plant cover from early seeded wheat is also effective for controlling wind erosion (Papendick, 1998). However, in tilled soils the sowing operation with deep-furrow drills tends to expose loose soil that is subject to suspension erosion until it is covered by plant growth or fall rains occur.

The soil loss ratio (SLR) is defined as the reduction in erosion, independent of soil erodibility properties, from the individual and combined effects of soil cover and random roughness compared with an unprotected, bare and smooth surface. The SLR for different rates of residue cover and levels of random roughness for soils on the Columbia Plateau was determined from wind tunnel data (Horning et al., 1998). Its relationship to these variables is expressed mathematically in equation 3.2 and in Table 3.1 in Chapter 3. Further details of the SLR concept and its application in estimating erosion reduction are presented in Papendick (1998, Chapter 4, Managing Soil Cover and Roughness).

Field measurements of soil cover and surface roughness are highly variable and can involve considerable time and effort. Therefore, simplified methods such as estimates from grain yields (and others subject to human bias and error) are often employed to obtain field values of these parameters (e.g., judgmental observation or comparison with standard photographs). The

SLR concept is not intended to provide precise values of erosion reduction from soil cover and roughness but rather estimates that are useful for evaluating the effectiveness of conservation farming practices in reducing erosion. For example, with 30% flat residue cover and soil with a smooth surface, the reduction in erosion is about 16% of that for the same soil with no residue cover (Table 3.1). If the 30% cover is in combination with a cloddy soil surface from rough tillage, the erosion is reduced to a few percent of that from a bare, unprotected soil surface. With 50% flat cereal residue cover and a smooth surface, the estimated wind erosion is less than 10% of that for the same soil with no residue cover.

Standing or leaning residues with some height [5 inches (13 cm) or more] are considerably more effective than flat residues in controlling erosion because the height obstruction reduces the speed of even high winds to near zero at the soil surface (Fig. 4.1). However, there is little quantitative data for assigning erosion reduction values based on characteristics such as stubble height, density and diameter of stems. Field observations indicate that wind erosion is near zero and not a problem where standing and undisturbed stubble from even low-yielding crops is present. For this reason, quantification of standing stubble effects on wind erosion is probably not a priority issue except possibly at very low residue rates, e.g., less than 10 to 15% of equivalent values for flat residue cover.

An important consideration in the application of wind erosion control measures on erosion-prone soils is the extent of PM emissions. Papendick (1998) reported the results of emission simulations made with the CP₃ regional air quality model that compared effects of residue cover rates on fallow for two highly erodible soils on the Columbia Plateau (L1 and L2, see Figure 1.4, Chapter 1) during several high intensity wind events. In two simulations, increasing residue cover from 5% to 25% on these soils reduced the 24-hr average PM₁₀ concentration in Spokane, WA by approximately 60% from the measured values of about 265 $\mu\text{g m}^{-3}$ in one storm and 260 $\mu\text{g m}^{-3}$ in another. The simulated values of PM₁₀ for the 25% residue cover were 110 $\mu\text{g m}^{-3}$ in one storm and 100 $\mu\text{g m}^{-3}$ in the other, both below the maximum allowable 24-hr limit of 150 $\mu\text{g m}^{-3}$. The SLR value for 25% flat residue



FIGURE 4.2. Seed-zone water content in fallow is measured by a research technician in late August in one-inch increments to a depth of eight inches. Adequate seed-zone water at depths of six inches and more is critical to establishment of early-planted winter wheat. Photograph by W.F. Schillinger, WSU.

cover on a smooth surface (late fallow condition) is 0.21 (Table 3.1) or a predicted reduction of about 80% of the soil loss from a bare, unprotected soil of the same type. With 50% residue cover (SLR = 0.06, or a reduction in soil loss of about 94% of that from a smooth, bare surface soil of the same type) for all fallow on the Plateau drylands, the predicted 24-hr average PM₁₀ concentration during an exceedance from a major dust storm was reduced by approximately 80% compared with the base level of 5% cover at two monitoring sites in Spokane, WA (from 280 µg m⁻³ to 50 µg m⁻³ at one site, and 420 µg m⁻³ to 90 µg m⁻³ at the second site; Papendick, 1998).

The SLR relationships together with simulations using the regional air quality model provide a vital piece of information, i.e., that relatively low rates of residue cover (around 30%) on relatively smooth soil (late fallow soil condition) can significantly reduce wind erosion on farmlands, enough to reduce 24-hr average PM₁₀ emissions below the NAAQS limit of 150 µg m⁻³ during major dust storms. Consequently, 30 to 50% cover should provide significant reductions in wind erosion and dust emissions even during severe windstorms.

Thus, widespread application of BMPs that would maintain a minimum of 30% equivalent cereal residue cover [the standard accepted rate for protection on highly erodible soils (CTIC, 2002)] at even marginal levels of soil roughness should provide sufficient soil protection to bring PM emissions on the Columbia Plateau into compliance with federal air quality standards, except possibly for extreme wind events. In conclusion, we believe that the 30% minimum residue cover after seeding and supplemented with surface roughness is a reasonable criterion for designing BMPs to control wind erosion and PM emissions from cropland soils.

WINTER WHEAT–FALLOW SYSTEMS

MINIMUM AND DELAYED CONSERVATION TILLAGE HIGHLY RECOMMENDED AS A BMP REPLACEMENT FOR CONVENTIONAL TILLAGE WINTER WHEAT–FALLOW

Intensive (often synonymous with conventional) tillage during fallow tends to bury significant quantities of crop residue and reduce surface roughness that increases the potential for wind erosion on most soil types. The

benefits of conservation farming for controlling erosion during fallow are well known, but conventional tillage continues to be practiced on significant acreages of cropland on the Columbia Plateau (Janosky et al., 2002). Reasons cited by growers for not adopting conservation practices include inadequate seed-zone moisture for early planting (Fig. 4.2); difficulty in controlling grass weeds, plugging of grain drills due to excessive residues; and concerns about the financial risk in converting to conservation farming systems (Janosky, et al., 2002; Juergens et al., 2001; Ogg, 1993). Until the late 1990s quantitative documentation on the combined erosion control and economic benefits of alternative conservation tillage systems for winter wheat–fallow was largely unknown.

A 6-year field study was completed in 1999 at the WSU Dryland Research Station at Lind, WA that compared the feasibility and economics of conservation tillage with conventional tillage for wheat–fallow (Janosky, et al., 2002; Schillinger, 2001a).

Conventional tillage. There are variations of conventional tillage fallow but a typical system on Shano silt loam soil (coarse-silty, mixed, mesic, Calciorthidic Haploxerolls, among the most erodible in the region) utilized in the Schillinger (2001a) experiment was 1) sweep tillage in August following winter wheat harvest using 14-inch sweeps set 5 inches deep at 12-inch spacings (done only if weeds

were present); 2) chiseling in November with straight point shanks spaced 2-ft apart and set 10 inches deep; 3) a glyphosate (Roundup) herbicide application at 12 oz ac⁻¹ in late winter to control late fall and winter germinating weeds; 4) primary tillage in March with a cultivator (two passes) equipped with overlapping 7-inch sweeps and trailed by a 5-bar spring-tooth harrow, or one pass with a tandem disk at a depth of 5 inches; 5) a shank anhydrous ammonia application in April; and 6) rodweeding at a depth of 4 inches, one pass each in May, June and July. Winter wheat was sown with a deep-furrow drill in early September. In all there were as many as eight tillage operations during fallow not including sowing (Table 4.1).

The conventional treatment was compared with the agronomic and economic performance of two conservation tillage systems: minimum tillage and delayed minimum tillage. The quantity of surface residues and the level of soil surface roughness during fallow were measured in all treatments.

Minimum tillage. Herbicides were used if needed, to control weeds after wheat harvest. Either a chisel operation, straight point with 4-ft shank spacings to a depth of 10 inches, or one with a rotary subsoiler that created a 16-inch deep pit every 8 ft² was performed in November of the harvest year. Herbicide was used to control weeds in late winter.

Table 4.1. Field operations for three fallow tillage systems at Lind, WA during 1993-1999¹.

Month	Fallow tillage system		
	Conventional	Minimum	Delayed minimum
July	Wheat harvest	Wheat harvest	Wheat harvest
Aug	Sweep (if needed)	Herbicide (if needed)	Herbicide (if needed)
Sept			
Oct			
Nov	Chisel (narrow spacing)	Chisel (wide spacing)	Chisel (wide spacing-used 3 in 6 yrs)
Dec			
Jan			
Feb	Herbicide	Herbicide	Herbicide
March	Cultivator (2 passes) or tandem disk	Undercutter	
April	Shank ammonia ²		
May	Rodweed	Rodweed	Undercutter
June	Rodweed	Rodweed	Rodweed
July	Rodweed	Rodweed	Rodweed
Aug			
Sept	Sow	Sow + ammonia ²	Sow + ammonia ²

¹Source: Schillinger (2001a).

²Aqua ammonia fertilizer.

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Primary tillage in March consisted of one operation with an undercutter equipped with overlapping 32-inch V-blades set at a depth of 5 inches and followed by a rolling harrow (Fig. 4.3). The remaining operations were three

rodweedings to a depth of 4 inches in each of May, June and July followed by sowing wheat and simultaneously applying aqua ammonia with a deep furrow drill in early September. In all there were five tillage operations with

minimal soil mixing in addition to sowing and fertilizer application (Table 4.1).

Delayed minimum tillage. The delayed minimum tillage system also employed herbicides for weed control after harvest, and chiseling at 4-ft shank spacings to a depth of 10 to 16 inches in only three of the six years. Herbicide was used to control weeds in late winter followed by primary tillage in May using an undercutter with overlapping 32-in V-blades to a depth of 5 inches trailed by a rolling harrow (Fig. 4.3). This was followed with two rodweedings at a 4-inch depth in June and July, with wheat sowed and aqua ammonia simultaneously applied with a deep-furrow drill in early September. In this system there were three and in some years four tillage operations with minimal soil mixing in addition to sowing plus fertilizer application (Table 4.1).

Effects of tillage systems on soil loss ratios. Table 4.2 shows residue mass, approximate cover, SLRs and grain yields for the three tillage treatments after sowing winter wheat in early September at the end of the 13-mo fallow season. Surface residue cover was consistently and significantly higher for the minimum tillage and delayed minimum tillage treatments compared with conventional tillage. Percent cover after sowing wheat mostly exceeded the 30% minimum residue cover standard for all six years with minimum and delayed minimum tillage, compared with conventional tillage that attained 30% cover only two out of six years (Fig 4.4).

Wheat yields, and thus, residue levels at the beginning of fallow, were lowest after the 1993-94 and 1995-96 fallow cycles. The SLR values for the treatments show that the erosion potential is low even in the drier years with both minimum tillage and delayed minimum tillage compared with conventional tillage. The differences in erosion control potential between the conservation and conventional tillage treatments are mainly due to surface cover but there is an added benefit from increased soil random roughness with minimum and delayed minimum tillage.

Agronomic results. Conventional tillage showed no agronomic advantages over the minimum tillage and delayed minimum tillage fallow



FIGURE 4.3. The V-sweep undercutter used in the winter wheat-fallow experiment at the WSU Dryland Research Station at Lind, WA significantly increased surface residue during fallow compared with conventional tillage and had no adverse agronomic or economic effects. A rotary harrow is attached behind the undercutter to break large soil clods and reduce air voids. The rotary harrow should not be used on lighter textured soils such as the Shano silt loam, where soil clods are difficult to maintain. Photograph by W.F. Schillinger, WSU. See Figure 1B in Appendix B for additional detail.

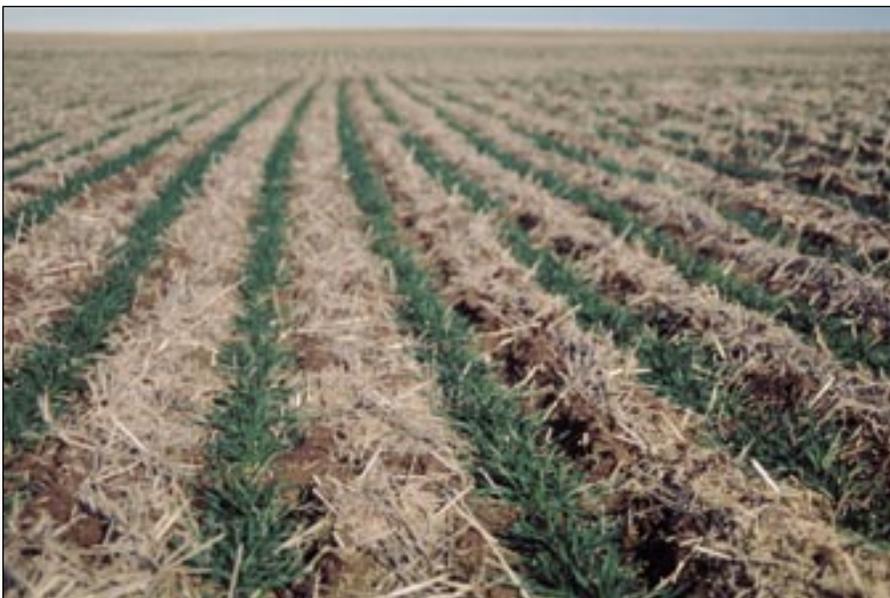


FIGURE 4.4. Winter wheat seedlings in the minimum tillage fallow treatment. This BMP provides adequate protection against wind erosion after sowing that improves as the wheat plants develop cover. Percent cover after sowing wheat achieved or exceeded the 30% minimum residue cover standard for all six years of the experiment with minimum and delayed minimum tillage, compared with conventional tillage that attained 30% cover only two out of six years. Photograph by W.F. Schillinger, WSU.

Table 4.2. Residue mass, percent cover and soil loss ratios (SLR) after sowing winter wheat as affected by conventional tillage, minimum tillage, and delayed minimum tillage in a winter wheat-fallow system on Shano silt loam soil¹.

Year	Tillage system									
	Conventional			Minimum			Delayed minimum			
	Residue mass and cover									
	lb/ac ²	%	SLR ³	lb/ac	%	SLR	lb/ac	%	SLR	bu/ac ⁴
1994	210	12	0.40	590	32	0.07	670	35	0.05	–
1995	380	22	0.24	700	37	0.06	800	40	0.04	27
1996	290	17	0.30	560	30	0.08	580	31	0.06	54
1997	560	30	0.16	1550	62	<0.03	1520	61	<0.02	76
1998	1130	52	<0.06	1270	57	<0.03	1260	57	<0.02	55

¹The data were reworked from Schillinger (2001a)

²Residue amounts at the end of fallow were multiplied by 0.75 to account for loss from deep-furrow sowing.

³Soil loss ratio based on a random roughness of 0.25 for conventional tillage, 0.75 for minimum tillage, and 1.00 for delayed minimum tillage.

⁴Average for all treatments.

Table 4.3. Mean market returns over variable and total costs per rotational acre for winter wheat from 1995–1999 as affected by fallow tillage system¹.

Fallow tillage System	Gross Return	Net returns over cost	
		Variable	Total
-----\$/ac-----			
Conventional	100.30	41.86	-11.04
Minimum	105.13	42.09	-10.78
Delayed minimum	99.42	35.64	-14.66

¹Adapted from Janosky et al. (2002). The economic results are from analysis of the Schillinger (2001a) field data.

in terms of weeds, diseases and grain yields. Averaged over five years the soil water content in the seed zone as well as total storage was not affected by tillage treatment (Schillinger, 2001a). However, chiseling in late fall with straight-point shanks increased over-winter water storage in two of six years when there was potential for runoff from frozen soils, but not in four winters when soils did not freeze.

There were no significant differences in grain yields among the treatments within any year or in the 5-yr average (Table 4.2) even though the yields for the minimum tillage treatment tended to exceed or equal those for the conventional treatment each year. Weeds were successfully controlled in all years of the experiment, primarily by cultivation in the conventional system and effectively with herbicides and limited cultivation in the minimum and delayed minimum tillage fallow systems.

Economic results. Economic analysis showed that the average five-year market returns over total production costs for the three tillage systems were equivalent when wheat prices were held at a 5-yr average price

of \$3.92 bu⁻¹ (Table 4.3; Janosky et al., 2002). Their data show that net returns over variable costs were similar for the conventional and minimum tillage systems but significantly less with delayed minimum tillage. Variable costs include seed, fertilizer, herbicides, insurance (crop, fire, hail), fuel, repairs and labor. When measured by net returns over total costs the conventional and minimum tillage systems are similar, and higher by about \$4 ac⁻¹ than for the delayed minimum tillage system although the difference is not statistically significant. Total costs include the variable costs comprised of a wage for the operator, a land rent charge, machinery fixed costs, and overhead.

The economic data clearly indicate that the potential soil erosion control benefits of the two BMP systems were obtained without foregoing any profit. Moreover, with the BMP systems there is little or no risk of losing government farm program payments due to non-compliance with residue cover requirements. The profitability of the minimum tillage system was statistically equivalent to the conventional system for both net returns over variable and

total costs indicating that no subsidies should be needed as an incentive for growers to switch from the conventional to the minimum tillage system (Janosky et al., 2002).

Summary. The results of this 6-year field study established that with judicious use of herbicides, fallow tillage on the highly erodible Shano silt loam soil of the Columbia Plateau can be reduced from the typical eight or more operations with conventional tillage to as few as three to five with the minimum or delayed minimum tillage systems without economic loss to the grower. With less tillage and use of the wide-blade V-sweep the reduced tillage systems significantly increased the surface residue cover and soil surface roughness during fallow and after sowing winter wheat. Application of these conservation systems on wheat-fallow acreages will provide marked reduction in wind erosion and significant improvement in regional air quality. Encouraging the use of these practices in the traditional wheat-fallow areas should be given high priority in conservation and regulatory policy issues and be highly recommended in extension education programs.

EARLY PLANTING AS AN ADJUNCT TO CONSERVATION TILLAGE FALLOW

Early planting of winter wheat is practiced by many growers on the Columbia Plateau and is recommended for conservation tillage fallow unless limited by insufficient seed-zone water, or the need to control winter annual grass weeds (Fig. 4.5). Studies show that sowing date and rate affects both the grain and straw yield of the crops as well as early biomass production for wind erosion control following the fallow season.

Straw and grain production. A 3-year field study conducted at the WSU Dryland Research Station at Lind, WA during the growing seasons 1994-95, 1995-96, and 1996-97 showed that the greatest effect of sowing date for four winter wheat cultivars (Buchanan, Eltan, Hatton, Moro) was on straw production (Donaldson et al., 2001). Straw yield from mid-August sowing averaged 3.0 t ac⁻¹ compared with 2.1 and 1.2 t ac⁻¹ from mid-September and mid-October sowing, respectively.

All cultivars produced less straw with delay in sowing date and when averaged across sowing dates and rates, straw production remained relatively

Table 4.4. Barley grain yield, and total surface residue after harvest relative to the conventional treatment (CT), and year-old residue after harvest in 1996 and 1997 as affected by conventional and no-till sowing method with different drills into spring barley and winter wheat stubble^{1, 2}.

Drill	Relative grain and residue yields					
	Sown into spring barley stubble			Sown into winter wheat stubble		
	Grain residue	Total Residue	Yr-old residue	Grain Residue	Total	Yr-old
1996	-----% of CT-----		% of total	-----% of CT-----		% of total
CT	100a ³	100a	17c	100a	100a	18b
No-till						
Flexi-coil⁴	93b	103a	29b	87b	102a	31a
JD 752⁵	94b	101a	26b	82b	93b	36a
JD HZ	76c	97a	36a	78b	93b	35a
P-value	0.023	NS	0.003	0.001	0.016	0.001
1997						
CT	100b	100b	12c	100b	100c	17c
No-till						
Cross slot⁶	117a	144a	36a	116a	182a	55a
Concord 1100⁷	110a	128a	32b	116a	159b	52b
JD HZ	92b	129a	35ab	96b	143b	51b
P-value	0.023	0.001	0.001	0.044	0.003	0.005

¹Data reworked from Schillinger et al. (1999a).

²Barley grain yields for the conventional treatment were 1.80 and 1.65 t ac⁻¹ in 1996 and 1.65 and 1.48 t ac⁻¹ in 1997 sown into spring barley and winter wheat stubble, respectively. Total residue yields for the conventional treatment were 4,460 and 3,980 lb ac⁻¹ in 1996 and 4,360 and 4,580 lb ac⁻¹ in 1997 sown into spring barley and winter wheat stubble, respectively.

³Numbers in a column followed by the same letter are not significantly different.

⁴Flexi-coil, Saskatoon, SK S7K 3S5, Canada

⁵John Deere Co., Moline, IL 61265

⁶Baker No-Tillage Ltd., 50 Nannestad Line, RDS, Fellding 5600, New Zealand

⁷CaseIH-Concord, Fargo, ND 58102; equipped with Anderson openers, Anderson Machine, Inc., Andover, SD.



FIGURE 4.5. Early planted winter wheat (in mid-to late-August in this photograph) significantly increases straw and grain production of the future crop compared with plantings in September or October. Moreover, with early planting, green cover is often adequate to reduce wind erosion from fall storms. Photograph by W.F. Schillinger, WSU.

constant among cultivars within each year. Moro generally produced the least straw but not less than Hatton in two years. Production from the August sowing was more than double that from the October sowing in all years and decreased approximately 30% per month to 71 and 42% of the August amount for September and October sowings, respectively. The low seeding rate of 20 lb ac⁻¹ reduced straw production at all sowing dates by an estimated 10 to 15% from the medium (40 lb ac⁻¹ and high (60 lb ac⁻¹) rates where production was similar.

Grain yields from the mid-August sowing of approximately 57 bu ac⁻¹ in 1995 and 80 bu ac⁻¹ in 1997 were significantly higher compared with those of 43 and 39 bu ac⁻¹, in 1995, and 68 and 57 bu ac⁻¹ in 1997, for the mid-September and mid-October sowings, respectively. The mid-October sowing produced the lowest yields in all years. Yield was always highest with the semi-dwarf Eltan whereas those for Hatton and Moro were similar for all sowing dates and in all years. Grain yield was not reduced by the low sowing rate in August but was reduced compared with the medium and high sowing rates in September and October.

The Donaldson et al. (2001) study clearly shows that sowing winter wheat in mid-to-late August using a medium sowing rate is effective for maximizing straw and grain production of winter wheat. Cultivars with high grain yield potential tend to be good straw producers. Maximizing straw production along with conservation tillage management during fallow helps to ensure year-round cover to control wind erosion in a winter wheat-fallow cropping system. If the need for straw is not a factor sowing may be delayed until mid-September without affecting grain yields. Moreover, there was no advantage to using the high sowing rate of 60 lb ac⁻¹ compared with the 20 or 40 lb ac⁻¹ rates for grain yield but the lowest sowing rate produced the least straw on all sowing dates.

Green cover. Green cover from winter wheat emerging in late August/early September can provide additional protection against wind erosion during the critical period following fallow. Wheat cultivars that emerge rapidly from deep planting offer the best potential for successful stand and green cover establishment under dry conditions typical of the Columbia Plateau. The important variables that determine percent cover include date of sowing

(degree days), row spacing and sowing rate. A wheat growth model developed by the USDA-ARS and Oregon State University at Pendleton, OR predicts percent cover based on these factors (Rickman and Rasmussen, 1985).

The model uses 120 degree days to wheat emergence, and adjusts for sowing rate and row spacing. For example, their model calculations show that it requires 380, 600 and 850 degree days to achieve 15, 25, and 72% ground cover, respectively. Based on long-term average temperatures and a sowing rate of 60 lb seed ac⁻¹ and 10-inch row spacing, the 15% cover would be achieved by mid-November at Pendleton, OR by sowing on October 1, the 25% cover by sowing on September 15, and the 72% cover by sowing on September 1.

It is obvious that a delay in sowing date markedly reduces the amount of cover because early biomass accumulation is slow and because temperatures decrease rapidly after mid September. Increasing the row spacing to 14 inches reduces the percent cover for the early sowing date to 64% but has little effect on the later planting dates. According to the model, percent cover is significantly increased by using higher sowing rates, e.g., 80 lb ac⁻¹ (Rickman and Rasmussen, 1985). Pendleton, OR is more southerly with generally higher temperatures than most of the drylands on the Columbia Plateau. Therefore, the rates of cover development will likely be greater than in the more northerly portions of the region.

CHEMICAL FALLOW

Chemical fallow which substitutes herbicides for tillage to control weeds continues to be under consideration as a BMP because of its potential to markedly reduce wind erosion (and water erosion) in fallow cropping systems. Since the soil is disturbed only minimally during a sowing/fertilizing operation, a continuous residue cover can be maintained on the land. Drawbacks to its practical use are usually attributed to agronomic and economic factors. A herbicide program for weed control tends to be more expensive than one in combination with tillage in dryland cropping systems because of the overall lower yields compared with areas receiving higher precipitation. With chemical fallow, moisture is often inadequate for early planting of wheat because of greater losses of water from the seed-zone during the summer compared with tilled soil (Hammel et al., 1981; Papendick et al., 1973). A delay in planting until October awaiting rains for seed germi-

nation reduces wheat yields by up to 25% (Donaldson et al., 2001).

Growers in the wheat-fallow areas have had limited success with chemical fallow while its use in the intermediate and higher precipitation zones (>12 inches) has been more favorable. For example, on lighter-textured soils, grower Paul Williams farming in Lincoln and Spokane counties with 15–18 inches of average annual precipitation, successfully manages a winter wheat-spring barley (*Hordeum vulgare* L.)- chemical fallow in a direct seed system with a Yielder® no-till drill (Malloy et al., 2000a). He also uses chemical fallow on heavier-textured soils but less frequently because of improved soil moisture conditions.

During chemical fallow, the grower applies an average of two applications of Roundup and 2,4-D herbicide in dry years and three in wet years with the first in late May, the second in late June-early July, and if summer rains occur, the third just before sowing that is done in early to mid-September. Mr. Williams notes from experience that soil moisture is deeper below the surface in chemical fallow than in conventional tilled fallow in the summer, though differences are less in the fall when the soil cools.

On another farm in Walla Walla County, in a 15-in average annual precipitation zone, the Thomases', Mike Sr., and Mike Jr., changed from a 2-year winter wheat-chemical fallow rotation to a 3-year winter wheat-spring wheat-chemical fallow rotation (Malloy et al., 2000b). Sowing is done with a shop-built chisel type no-till drill. Downy brome (*Bromus tectorum* L.) and jointed goatgrass (*Aegilops cylindrica* Host.), persistent weeds in the 2-yr rotation, are controlled with herbicide before sowing spring wheat and then in the chemical fallow.

These growers typically spray for weed control three times during chemical fallow: early spring, early summer, and late summer with a mixture of Roundup and 2,4-D. Banvel is included in the early summer application to control China lettuce (or prickly lettuce, *Lactuca serriola*) and maretail (or horse weed, *Conyza canadensis*). The growers follow a standard postemergence herbicide program for winter and spring wheat. The Thomases' believe that fallow tillage did not conserve more seed-zone moisture than chemical fallow to enable early establishment of winter wheat.

There are no reports of successful use of chemical fallow in the dry areas

(<12 inches average annual precipitation) but interest is high among growers for further research on this practice. One environmental concern with chemical fallow is that its dependence on herbicides can exacerbate problems with water pollution, chemical drift, and human and wildlife safety and health. In this regard, chemical fallow remains a research topic today in terms of how it could be utilized as a profitable winter wheat (or spring crop) management practice with its advantages for wind erosion control.

Research is underway at WSU to explore how seed-zone water can be conserved by managing soil/residue properties at the soil surface during chemical fallow. Most past research was short-term (one to three years on a site). This was not long enough to investigate changes in thermal and hydraulic properties in the surface layers with residue and duff accumulation that may occur over the long-term (10 to 20 years) and how such changes might impact seed-zone water content during fallow.

Additional research is underway to determine temperature and moisture requirements for germination and emergence of different winter wheat cultivars under dryland conditions. Another question to be addressed is: can the productivity of winter wheat germinating after October or November rains be increased through improved residue, weed, fertility and soil water management? Ongoing and future research should help to elucidate some of these long unanswered questions.

WINTER WHEAT-NO-TILL SPRING CROPPING SYSTEMS

Winter wheat with minimum or delayed tillage fallow, chemical fallow or without fallow in rotation with no-till spring cropping has potential as an effective BMP in a dryland crop production system. It retains winter wheat as a principal crop and compared with the wheat-fallow system additional potential benefits include: 1) increased cropping intensity with more cover on the land a greater percentage of the time; 2) improved water use efficiency; 3) improved soil quality; and 4) more effective erosion control in the traditional fallow areas.

WINTER WHEAT-SPRING BARLEY-FALLOW, OR WINTER WHEAT-SPRING BARLEY-SPRING BARLEY

According to Schillinger et al. (1999a) spring barley is well-adapted to the 12-inch and higher precipita-

CHAPTER 4

tion zones, and with no-till sowing has the potential to improve economics when produced in rotation with winter wheat. Cropping options include winter wheat–spring barley–fallow, or a second year of barley in place of fallow the third year.

An experiment was conducted in 1996 and 1997 at two sites comparing the agronomic performance of spring barley sown into conventionally tilled seedbeds with a double disk drill, or into standing stubble with several types of no-till drills where the previous crop was either winter wheat or spring barley (Schillinger et al., 1999a). The experimental sites, two for each year, one after barley and one after winter wheat, were located on the Donald and Doug Wellsandt farm in Adams Co., Washington on Walla Walla silt loam soil (coarse-silty, mixed mesic Typic Haploxeroll). Precipitation was 13 and 19 inches at the sites in 1996 and 1997, respectively, compared with a 20-year average of 13 inches at a weather station about 2 miles away.

The surface cover in the two years while in the cropping cycle with no-till spring barley allowed adequate protection against wind erosion from even severe storms. Baseline surface residue in March from the previous crop was 2,160 and 2,840 lb ac⁻¹ for barley stubble and 3,220 and 4,670 lb ac⁻¹ for winter wheat stubble in 1996 and 1997, respectively (Schillinger et al., 1999a). With exception of the vegetative growth of barley during the growing season, residue amounts starting with the baseline in March and after sowing each year for either of the preceding crops, provided a minimum of 70 to over 93% soil surface cover (giving calculated SLRs of 0.02 and < 0.01, respectively) for all of the no-till treatments. Even with conventional tillage in the annual cropping phase, residue cover before crop establishment was adequate for protection against wind erosion.

Beginning in March of each year, seedbed preparation in 1996 with a V-sweep field cultivator and in 1997 with a tandem disk, each in combination with harrowing and followed by fertilizer injection and sowing, were calculated to reduce the baseline residue levels to about 48 (SLR = 0.07) and 58% (SLR = 0.03) for barley stubble, and 68 (SLR = 0.02) and 77% (SLR = 0.01) for winter wheat stubble, respectively. An allowance was made for added surface random roughness to 0.50 inch in 1997 compared with 0.25 inch in 1996 according to Schillinger et al. (1999a).

Total residue after harvest was higher for all no-till treatments compared with conventional tillage in 1997 (the higher rainfall year) but not in 1996 where a greater amount of residue after harvest of the conventional tillage treatment offset the difference (calculated from Table 4.4). However, all treatments provided over 90% ground cover at this time. Year-old residue as percent of the total after harvest was considerably higher in the no-till treatments compared with conventionally tilled fallow. Similar results were obtained when the crop was sown into winter wheat stubble compared with barley stubble in 1997 but not in 1996 (Table 4.4). The Cross-Slot™ no-till drill, known for its minimal disturbance of stubble retained more surface residue than the other no-till equipment although it was equal to the John Deere HZ treatment after barley stubble (Schillinger et al., 1999a; see Figure 2B in Appendix B for additional detail for the Cross-Slot no-till opener).

Both 1996 and 1997 were considered as favorable years for spring barley production in the dryland areas. With uniform stands, grain yields with no-till sowing into standing stubble with row-spacings up to 10 inches were generally equal to those from conventional tillage (Schillinger et al. (1999a). The conventional tillage system produced higher grain yields than no-till in 1996 but two no-till drills, the Cross-Slot and the Concord™ 1100, produced significantly higher yields than the conventional system in 1997. Though no economic assessment of these cropping systems was made, overall, the no-till barley yields are well within the range considered as profitable for growers.

These data suggest that there would be little risk from wind erosion during all seasons while the winter wheat–spring barley (or alternative spring crop) is in the annual cropping phase. This applies also to conventionally-managed systems that use shallow tillage and limit operations to conserve surface residues during spring crop stand establishment. The main concern with wind erosion and dust emissions is with the winter wheat cycle in the rotation. It is not economically feasible to follow barley with winter wheat because of the potential for volunteer barley plants to infest the wheat crop and the resulting seed contamination that would reduce its value to feed grain. Most growers will choose a year of fallow between the crops to control volunteer barley and other weeds, and to gain another year of over-winter

precipitation to enable early seeding of the winter wheat crop. In this case the BMP recommendation is to use the minimum or delayed minimum tillage fallow systems outlined in the previous section (Schillinger, 2001a) starting with the spring barley residue levels after harvest.

According to Schillinger's (2001a) fallow tillage research, winter wheat residue at the beginning of fallow ranged from about 1,950 to 5,100 lb ac⁻¹ during the six-year period, being lowest after a spring wheat crop when the study was initiated, and again in the 1995-96 fallow cycle. Of these amounts 750 to 2,070 lb ac⁻¹ remained on the surface of the minimum tillage and delayed minimum tillage treatments, respectively, at the end of the 13 month fallow period, which is a decrease in the residue biomass from the highest to the lowest of about 61%. Based on Table 4.2 these amounts of surface residue generally resulted in SLR values of under 0.10 after sowing winter wheat into fallow.

Total residue after harvest in the Schillinger et al. (1999a) intensive cropping experiment ranged from about to 4,300 to 5,700 lb ac⁻¹ and 4,000 to 8,300 lb ac⁻¹ with no-till sowing into barley and winter wheat stubble, respectively, during the 1996 and 1997 cropping seasons. Of these amounts, approximately 1,200 to 4,600 lb ac⁻¹ of year-old residue remained in the no-till treatments at what would normally be the end of the fallow season if a crop had not been grown. Thus, the total residue at what would be the beginning of the fallow season, and total residue at what would be the end of the fallow season with either two successive crops of no-till spring barley or one crop of no-till barley after winter wheat trended higher than those in the alternate winter wheat-fallow system with minimum, or delayed minimum tillage.

Though no experiment has been conducted to measure the actual surface cover from barley residue that would carry over a 13-mo fallow period, it seems reasonable that with minimum tillage or delayed minimum tillage, the amounts, and thus, the SLRs would approximate those for the winter wheat-fallow system using these practices. However, there are two caveats here. One is that in the Schillinger (1999a) intensive cropping experiments with barley both seasons received above average precipitation (though only 4% above average in the 1996 cropping season, but 52% in 1997), and two is that barley residue decomposes more rapidly than wheat

residue and less may be present at the end of fallow (Smith and Peckenpough, 1986). Therefore, minimum requirements for a BMP in a winter wheat–spring barley–fallow rotation (or two years of barley before fallow) are best met with the barley no-tilled into crop stubble followed by minimum tillage or delayed minimum tillage fallow with no more than three or four tillage operations.

NO-TILL WINTER WHEAT IN A CONTINUOUS ROTATION WITH SPRING CROPS

Some dryland growers have expressed an interest in bypassing fallow by utilizing a continuous no-till rotation of winter wheat with spring crops as a BMP option for more intensive cropping. This system provides ample cover throughout both cropping cycles for soil protection against even the most severe windstorms. The main concerns with this sequencing are primarily the agronomic and economic risks of low yields from inadequate moisture, crop pests (weeds, insects, diseases) associated with continuous no-till, and long-term income stability.

Data on the performance of this no-till system is limited. A study was initiated in 1998 at the WSU Dryland Research Station at Lind, WA that included no-till winter wheat in rotation with spring wheat starting in 1999 compared with continuous no-till spring wheat. All crops were sown with a Cross-Slot no-till drill. In 2000, a normal rainfall year, winter wheat sown after two consecutive crops of spring wheat yielded 40 bu ac⁻¹ compared with 24 bu ac⁻¹ for continuous spring wheat. The winter wheat yield compared favorably with the Station average of 48 bu ac⁻¹ for winter wheat after fallow.

In 2001 the no-till winter wheat crop followed three years of continuous no-till spring wheat. The drought that year reduced the yields of all crops in the low precipitation areas that did not follow fallow. In addition to the moisture deficiency, the winter wheat was severely damaged in the flowering stage by frost and yielded only 13 bu ac⁻¹ compared with 9 and 15 bu ac⁻¹ from no-till spring wheat after winter wheat and continuous spring wheat, respectively (Schillinger et al., 2001b). In 2002, winter wheat after three years of spring wheat yielded 15 bu ac⁻¹ that was significantly higher than continuous spring wheat at 9 bu ac⁻¹, and again in 2003, the yield of winter

wheat after three years of spring wheat at 16.3 bu ac⁻¹ was significantly higher than continuous no-till spring wheat at 8.5 bu ac⁻¹ (Fig. 4.6).

In addition to the Lind experiment winter wheat was incorporated into two no-till, continuously-cropped, 4 yr rotations of 1) two years of soft white winter wheat followed by two years of soft white spring wheat, and 2) soft white winter wheat followed by spring barley, yellow mustard (*Brassica hirta*), and soft white spring wheat. Included in this experiment are 2-year rotations of soft white spring wheat–spring barley and hard white spring wheat–spring barley, and continuous no-till spring crops of soft white and hard white wheat. The 2-year soft white spring wheat–spring barley rotation and the continuous no-till soft white spring wheat treatments were ongoing from earlier work started in 1997.

The 4-year rotations were implemented in 2001 on the Ron Jirava farm in Adams County, WA and the cycle will be completed in 2004. The first results in 2001 under drought conditions showed extremely low yield of all crops, but spring wheat in the second 4-year rotation at 12 bu ac⁻¹ significantly out yielded winter wheat in its rotation and one winter wheat crop in the first rotation (Table 4.5). The continuous spring wheat yield at 14 bu ac⁻¹ was significantly higher than all other wheat crops in the first 4-year rotation and winter wheat in the second 4-year rotation. Wheat yields in 2002 were higher than in 2001 and similar except for winter wheat that yielded 16 bu ac⁻¹ in the second 4-year rotation and was significantly lower than all others.

In 2003, no-till winter wheat out yielded spring wheat in the first 4-year rotation, and in the continuous no-till systems, but not where spring wheat followed chemical fallow (i.e., failed yellow mustard in 2002) (Table 4.5). The 7-year average yield of no-till soft white spring wheat in the barley rotation and continuous system were similar at 34 and 33 bu ac⁻¹, respectively. Yields of hard white spring wheat are similar to that of soft white spring wheat in the barley rotations but are considerably less in two years out of three in the continuous wheat systems.

In 2001, after sowing winter wheat into continuous spring wheat stubble, the seedlings survived the winter but were damaged by Rhizoctonia [*Rhizoctonia solani* (Kühn) AG8] root rot in the early spring and later adversely affected by a heavy infestation of

downy brome after an absence of the weed during five years of continuous spring wheat. Since 1999, Rhizoctonia has been a serious disease at the Jirava study site, with bare patches currently occurring on 10% of the land area (Cook et al., 2002; Fig. 4.7).

In summary, the yields of no-till winter wheat recropped after spring wheat at Lind in 2000, 2002, and 2003, and after spring wheat and winter wheat in continuous cereal cropping at the Jirava site in 2003, were significantly higher than those for continuous no-till soft white spring wheat. However, it is premature to draw firm conclusions from these preliminary results, especially with one season of severe drought. While some of the yields may not always appear promising, the no-till annual grain cropping systems warrant further research because of potential environmental benefits for wind erosion control and future improvements to soil quality. Moreover, these systems retain winter wheat in the rotation, the crop that is favored by many growers in the dryland region.

CONTINUOUS NO-TILL SPRING CROPPING SYSTEMS COMPARED WITH MINIMUM TILLAGE FALLOW: THE RALSTON FIELD STUDY

In the mid-1990s USDA-ARS and WSU scientists proposed continuous no-till spring cropping as a possible alternative to the traditional winter wheat–fallow system in areas with less than 12 inches of annual precipitation. It was hypothesized that the additional water saved with no-till in combination with producing spring cereals adapted to the dry zone would reduce the risk of crop failure and economic uncertainty in the low precipitation zone.

Continuous no-till annual spring cropping systems, where adaptable, offer a number of potential benefits for growers and society. The erosion problem (wind or water) is essentially eliminated as the soil is protected throughout the year with cover from undisturbed crop residues during the non-growing season and residues and crop canopy during the growing season. Problems such as poor stand establishment from drought and winter-kill, and troublesome winter annual grass weeds and crop diseases affecting winter wheat would be greatly minimized or eliminated. In

Table 4.5. Yields of winter wheat and spring rotation crops in a continuous no-till system on the Ron Jirava farm in Adams County, WA, 2001-2003¹.

Rotation and crop ²	Year			7-yr ave ³
	2001	2002	2003	
4-yr I				
WW (bu ac ⁻¹)	7cde ⁴	21b	30ab	
WW (bu ac ⁻¹)	9bc ⁵	21b	29ab	
SWSW (bu ac ⁻¹)	8bcde ⁵	23ab	19d	
SWSW (bu ac ⁻¹)	10bc	23ab	25c	
4-yr II				
WW (bu ac ⁻¹)	5e	16c	28abc	
SB (t ac ⁻¹)	0.16 ⁵	0.65	0.69	
YM (lb ac ⁻¹)	350	— ⁶	146	
SWSW (bu ac ⁻¹)	12ab	21b	31a ⁷	
2-yr I				
SWSW (bu ac ⁻¹)	12ab	25a	27abc	34
SB (t ac ⁻¹)	0.35	0.75	0.80	1.06
2-yr II				
HWSW (bu ac ⁻¹)	10bc	22ab	27abc	
SB (t ac ⁻¹)	0.27	0.78	0.83	
Cont. SW				
SWSW (bu ac ⁻¹)	14a	22ab	24c	33
HWSW (bu ac ⁻¹)	6cde	21b	18d	

¹Adapted from Schillinger (2002).

²WW = soft white winter wheat, SWSW = soft white spring wheat, SB = spring barley YM = yellow mustard, and Cont. SW = spring wheat, HWSW = hard white spring wheat.

³Continuous spring wheat and spring wheat–spring barley rotation have been ongoing since 1997.

⁴Within column wheat yields followed by the same letter are not significantly different at the 5% probability level.

⁵Followed spring wheat, not winter wheat during the first year of the 4-yr rotation.

⁶No crop was produced because frost killed yellow mustard in 2002.

⁷The 2003 spring wheat after yellow mustard was essentially after chemical fallow since the yellow mustard was killed by frost in the seedling stage in 2002.

addition, with no-till the soil shifts to sequestering carbon that should increase its organic matter content and improve soil quality and productivity over the long-term. Continuous no-till spring cropping in the drylands has received little or no research attention regarding optimum crop rotations and sequencing, crop variety adaptation, soil fertility and pest management, and system profitability compared with traditional winter wheat-fallow.

A new field research project initiated by F.L. Young, USDA-ARS, Pullman, WA began in August 1995 with continuous no-till spring cropping on large-scale, replicated plots near Ralston, WA in Adams County (Fig.4.8). The site was on the Curtis Henning farm on Ritzville silt loam soil in an 11.5-inch average annual precipitation zone. The first five years (1996-2000) of the project are referred to as Phase I which evaluated four crop rotations: 1) soft white winter wheat–minimum tillage fallow (SWSW–MTF), 2) no-till soft white spring wheat–chemical fallow (SWSW–CF), 3) continuous no-till hard red spring wheat (HRSW), and 4) continuous no-till hard red spring wheat–spring barley (HRSW–SB). Data for SWSW–CF is only reported through 2001 after which there was a change in the treatment. All of the cropping systems qualify as BMPs because of residue cover and additional surface roughness with the MTF.

Tillage in the winter wheat–fallow rotation followed a system of minimum tillage developed by the grower-cooperator that was similar in respects to the delayed minimum tillage system of Schillinger (2001a). In some years the spring tillage was delayed longer and rodweeded only once compared with the Schillinger treatment. Sowing and fertilizer application for the continuous no-till spring cereals were made in one pass with a modified John Deere 9400 Series hoe drill (Fig. 4.9). Standard experimental procedures (pest monitoring and control, soil fertility testing and nutrient application, grain and protein sampling) and field equipment in common use by growers in the area were utilized in the plot operations. Attention was given to weed species shifts and population dynamics and preventing herbicide resistance in weeds. Crop varieties were selected from those that have demonstrated the best performance for the area. Measurements included soil water and organic matter dynamics of the different systems.

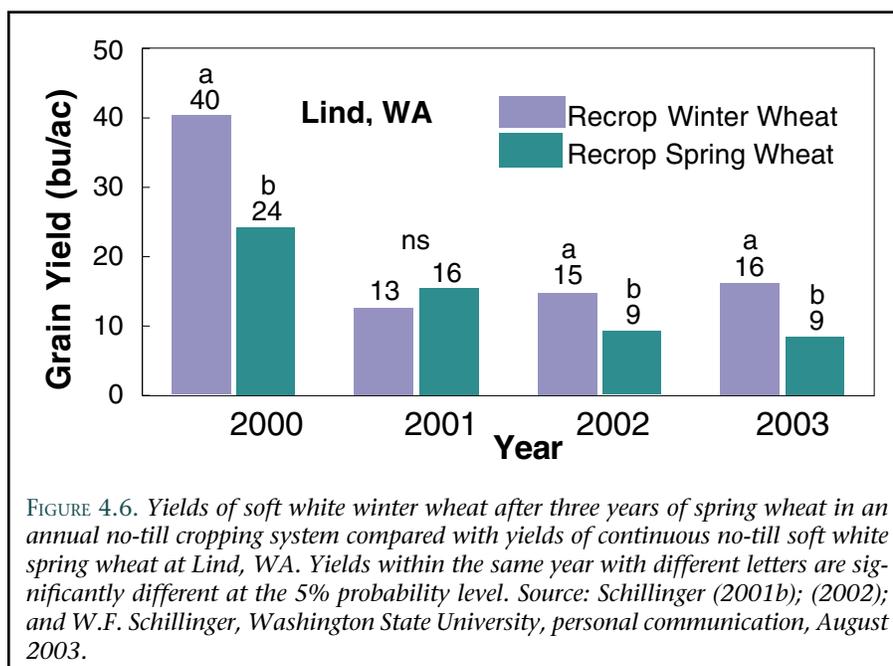


FIGURE 4.6. Yields of soft white winter wheat after three years of spring wheat in an annual no-till cropping system compared with yields of continuous no-till soft white spring wheat at Lind, WA. Yields within the same year with different letters are significantly different at the 5% probability level. Source: Schillinger (2001b); (2002); and W.F. Schillinger, Washington State University, personal communication, August 2003.

SUMMARY ON AGRONOMIC ASPECTS FOR THE DIFFERENT CROPPING SYSTEMS

Some of the highlights on the soil and crop management aspects of cropping systems research at the Ralston site are summarized as follows (Young et al., 1999, 2000, 2001b; Young and Pan, 2002):

1. The precipitation and growing conditions during 1996–2000 were generally favorable for spring crops and their 5-year yield averages met or exceeded expectations for the area (Fig. 4.10). However, yields for all crops, especially the spring cereals were markedly reduced by drought in 2001 and were only slightly higher in 2002 (except winter wheat) due to improved moisture conditions. Average yield reductions for the two dry years were about 50% for winter wheat and over 70% for the spring crops mainly because crop year precipitation was 37% below normal in the September 1, 2000 to August 31, 2001 growing season and 20% below normal for the season in 2001–02. The coefficient of variation values (CV) in Figure 4.10 indicate that by including the two low precipitation years the yield risk was at least doubled that

of the previous five years, reaching 44 to 54% for spring crops and 30% for winter wheat.

2. The protein content of continuous HRSW averaged 15.5% during 1999–2001 over a range of 15.1 to a high 16.5% in 2001. In the spring barley rotation it ranged from 14.2 to a high of 15.2 in 2001 for a 3-yr average of 14.7%.
3. The 5-year average (1996–2000) for water storage in the soil was 29% of the precipitation for the 12-month fallow period for winter wheat compared with 18% for the same period with chemical fallow for spring wheat. Given the 5-yr average precipitation of 12.8 inches, this amounts to nearly 1.5 inches of additional water stored in the SWWW–MTF per season compared with the SWSW–CF system. The difference in water storage between the two systems was attributed to higher evaporative loss combined with water use by broadleaf weeds (mostly Russian thistle) in chemical fallow. Only 55% of the winter precipitation was stored during the second winter of chemical fallow in the SWSW–CF system (18 month fallow). The 5-year average for the first year over winter water storage was 73% of the precipitation

for the SWWW–MTF system and essentially the same for the combined continuous no-till spring cropping systems.

4. After six years of cropping, steady state infiltration rates measured with a ponded infiltrometer were 0.02 inches min⁻¹ in winter wheat stubble (SWWW–MTF) and 0.04 inches min⁻¹ in continuous no-till HRSW stubble indicating more favorable surface conditions for water intake in the latter treatment.
5. Russian thistle in spring cereals and downy brome in winter wheat were the primary weeds and no species shift occurred in any of the systems during the seven-year study. Weeds were adequately controlled in all cropping systems with in-crop herbicides and post-harvest applications when necessary. The exception was chemical fallow for Russian thistle that is particularly difficult to control with herbicides during the hot summer months.
6. Experiments monitoring insects generally indicated that aphids [primarily English grain (*Sitobion avenae*) and Russian wheat (*Diuraphis noxia*)] were not a problem in winter wheat and that populations in spring cereals remained below economic levels (Young et al., 1999; 2000). During a 3-yr study in 1998–2000 tiller infestations of Hessian fly [*Mayetiola destructor* (Say)] increased to levels ranging from 15.6 to 47.5% of tillers infested in HRSW and SWSW where the economic injury level is estimated at 15 to 20% of tillers infested for spring wheat (Clement et al., 2003). ‘Baronesse’ spring barley was resistant to Hessian fly attack. Infestations of Hessian fly in winter wheat were low in 1998–99 but reached 27.6% of tillers infested in spring 2000. These results indicate the natural year-to-year variability that can be expected in populations of pest insects and that insertion of Hessian fly-resistant genes in crop cultivars can prevent economic loss from this particular species (Clement et al., 2003).
7. In pathology studies, the incidence of two diseases, Rhizoctonia root rot and take-all (*Gaeumannomyces tritici* var. *tritici*) were monitored in the continuous HRSW and HRSW–SB rotation as judged by percentage of infected plants (Young et al., 1999; 2000; 2001b). Rhizoctonia



FIGURE 4.7. Bare patches caused by *Rhizoctonia* root rot in spring barley in the long-term no-till cropping systems research project near Ritzville, WA. The patches at this site after three years of no-till occupy 10% of the field area. The disease appears to increase in the early years of continuous no-till spring cropping and affects both cereal and oilseed crops. There is no known control for the disease with continuous no-till cropping. Photograph by W.F. Schillinger, WSU.

root rot was more severe on barley than on wheat. Disease severity ratings were confounded by the differences in the cropping history prior to initiation of the field study in 1995. Winter wheat seedlings were damaged each year by a

root-pathogen complex including rhizoctonia root rot, take-all, and fusarium foot rot (*Fusarium pseudograminearum* and *Fusarium culmorum*). Though rhizoctonia root rot generally occurred on a high percentage of the plants, severity

ratings were low to intermediate, and damage to plants was usually minor. Damage from the individual diseases was not consistent for the different years. No assessment was made in the study to relate how disease incidence affected crop yields or the effectiveness of potential control measures.

8. Continuous no-till spring cropping offers a unique opportunity for controlling wind erosion and reducing PM dust emissions in the dryland areas through increased crop cover during periods of high wind erosion potential. Average surface cover with minimum tillage fallow was reduced to below 20% in two of four years illustrating that cover alone may be insufficient in some seasons to meet minimum erosion control requirements even when conservation measures are applied, and with normal or above normal precipitation (Thorne et al., 2003). However, random soil roughness significantly lowered the soil loss ratio during the fallow phase when residue cover was low. On the other hand, soil cover with continuous no-till HRSW and HRSW-SB approached 100% after the third crop cycle from a combination of new and old crop residues. Adequate surface cover for erosion control was also maintained with the SWSW-CF rotation although there was a significant decline in surface residues over the 18-month fallow period. The no-till rotations were subject to minor wind erosion from exposed furrows after sowing, but such susceptibility decreased rapidly when a crop canopy was established in late spring. Because random roughness declined during the three-year transition to no-till, residue cover and crop canopy were the dominant factors in reducing wind erosion in the no-till rotations (Thorne et al., 2003).
9. In a modeling study using conventional tillage fallow as a base for comparing dust emissions, it was estimated that the minimum tillage fallow would reduce PM emissions by 54% compared with 95% reduction with continuous no-till spring grain cropping (Lee, 1998).



FIGURE 4.8. Long-term, large scale, replicated plots comparing the agronomic and economic performance of annual spring cropping with conservation tillage winter wheat-fallow near Ralston, WA in a 11.5-inch annual precipitation zone. The study initiated in 1995-96 was the first in the region to test the feasibility of continuous no-till cereal cropping as an alternative to tilled winter wheat-fallow and spring wheat-chemical fallow systems in the low precipitation zone. Continuous no-till annual cropping provides year-round protection against wind erosion but unfavorable economics has limited its use in the dryland areas. Photograph by F.L. Young, USDA/ARS, Pullman, WA.



FIGURE 4.9. John Deere 9400 Series hoe drill used to sow the spring crop systems in the Ralston, WA field study. The drill though not specifically designed for no-till has performed well sowing into spring cereal stubble in terms of crop stands and range of residue levels. Photograph by F.L. Young, USDA/ARS, Pullman, WA.

ECONOMIC ANALYSIS

An economic analysis was conducted for the Ralston field data by comparing profitability of the continuous no-till spring cropping systems with the winter wheat-fallow

rotation as the standard (Young, 2001; 2002; Young and Pan, 2002). Table 4.6 shows the net returns over total costs for each cropping system during the first five years, and all seven years of the experiment except for SWSW–CF that was discontinued after 2001.

Costs and revenues are computed on a rotational acre basis; for example, costs and income for SWWW–MTF are calculated for one half acre of wheat and one half acre of fallow. For the HRSW–SB rotation, calculations are for one half acre of spring wheat and one half acre of barley. The grain prices are five-year marketing year averages with adjustments for protein content of hard red wheat. Government farm program payments of \$29 ac⁻¹ yr⁻¹, but no crop insurance, are included in the net returns for both periods. Costs are calculated based on the actual sequence of operations conducted on the research plots assuming typical farm-scale equipment used by local growers. Prices for variable inputs of fertilizer, herbicide, seed, fuel and a wage for the grower's labor are average rates for each crop and rotation during 1996–2000.

Table 4.6 shows that average net returns over total costs are negative for all three spring cereal systems, and positive for the winter wheat–fallow rotation that averaged a modest return of \$16.29 ac⁻¹ yr⁻¹ during 1996–2000 and then dropped to \$3.81 ac⁻¹ yr⁻¹ during 1996–2002 because of two successive dry years. Not shown in the table is that the losses per acre for continuous HRSW more than quadrupled in 2001 to –\$114.07 and in 2002 to –\$103.55 compared with –\$25.55 for the 1996–2000 average (Young, 2002). Losses were slightly lower with the HRSW–SB rotation during these two years. Prolonged drought increases the yield risk with spring cropping. Analysis by Young (2002) show that the overall disadvantage or loss for continuous HRSW compared with SWWW–fallow during 1996–2000 was \$42 ac⁻¹ (i.e., 16.29 – (–25.55) = \$41.84) which then increased to \$53 ac⁻¹ (i.e., 3.81 – (–49.36) = \$53.17) during 1996–2002.

However, as Young (2001) indicates, the profit reported, though negative, assumes that the grower receives a normal market return for all resources including owned land and equipment, and any unpaid labor. For some growers the negative profit values are of less concern since these may be offset by other anticipated or perceived benefits such as land value appreciation and possible lifestyle advantages, or future business ambi-

tions. Net returns over variable costs are often used as a short-term indicator of profitability when comparing the economics of cropping systems. However, net returns over total costs are a better long-term indicator of profitability because land debt service or rent and equipment replacement are ongoing major expenses that are not included variable costs.

In conclusion, the profitability of SWSW–CF rotation and all of the continuous no-till spring cereal cropping systems was considerably lower than the SWWW–MTF system. Higher yields and/or lower production costs are needed with the no-till spring cropping systems to improve their competitiveness with a reduced tillage winter wheat cropping system if these are compared solely on the basis of farm economics. However, if environmental benefits are considered, public valuation of improved air quality, lower health risks and possible cost-sharing inducements might persuade growers to shift away from wheat–fallow towards the continuous no-till cropping systems (Young, 2001).

A second part (Phase II) of the Ralston field study was initiated in 2001 and continued the continuous no-till HRSW and no-till HRSW–SB rotations and replaced the SWSW–CF with a no-till facultative spring wheat–no-till spring canola (*Brassica napus* L.) treatment for comparison with the previous standard conservation tillage winter wheat–fallow system. The HRSW plots were split to compare production and quality with normal versus reduced inputs. The new rotations included spring triticale (*xTriticosecale* Wittmack), spring canola, spring oat (*Avena sativa* L.) and spring mustard. However, drought in 2001 and 2002 severely affected several rotations and resulted in failures of most spring crops.

As a part of the project, a survey of dryland growers was conducted in 2002 to determine how the results and outcomes of the Ralston field study was impacting area growers in terms of feedback on new technologies, and changes by growers in crop and soil management and adoption of conservation practices for wind erosion control (Forté-Gardner, 2003). The overall assessment was that growers were highly supportive of the field project as a learning tool for managing soil moisture and controlling wind erosion while reducing risks involved with converting to alternative cropping systems. The survey also provided grower insights on directions for

future research based on the findings from Phase I.

As a result, grower input along with that of researchers and the regional drought during Phase II, has led to a current major redesign of the treatments for the next phase of the work (Forté-Gardner et al., 2003). Plots have been split to allow for new rotations and to test decisions related to crop selection, planting date, herbicide requirements, and marketing based on prevailing environmental and biological conditions.

The goal of the new research is to provide dryland growers with as many acceptable options as possible and thus, enhance their flexibility with conservation farming. The redesigned treatments include: 1) reduced-till winter wheat or winter canola–fallow; 2) no-till soft white spring wheat (flex crop) or chemical fallow–facultative spring wheat; 3) no-till hard red spring wheat with normal or reduced herbicide applications; 4) no-till spring oat (for forage or seed)–spring triticale; and 5) no-till hard white spring wheat–one pass, or no-till spring barley (Forté-Gardner et al., 2003). The new treatments will be showcased at the existing Ralston site in June 2004.

CONTINUOUS NO-TILL SPRING WHEAT COMPARED WITH WINTER WHEAT–FALLOW IN THE HORSE HEAVEN HILLS OF SOUTH-CENTRAL WASHINGTON STATE

The agronomic and economic performance of continuous no-till spring cropping was compared with traditional tillage winter wheat–fallow in the Horse Heaven Hills (HHH) of south central Washington where approximately 300,000 acres are dry-farmed for cereal production in one of the driest areas in the US, and for that matter the world (Schillinger et al., 2002; Young et al., 2001a). Long-term average annual precipitation ranges from 6 to 8 inches of which 70% occurs in the winter. Long-term yields of soft white winter wheat after fallow average between 18 and 25 bu ac⁻¹. Recurrent drought, limited plant residue, and tillage during fallow often leave little protection against wind erosion from the farmlands that lie upwind in a southwesterly direction from the Tri-Cities, WA with a population of more than 100,000.

Faced with hardship conditions most years, growers in the HHH have learned to survive by being some of

CHAPTER 4

the best soil conservationists on the Columbia Plateau. However, many seek alternatives to the winter wheat-fallow system due to its inefficient use of limited water, difficulties with winter wheat stand establishment, and frequent severe wind erosion from lack of surface cover and soil roughness.

A 6-year experiment comparing conventionally tilled soft white winter wheat-fallow (SWWW-F) with continuous no-till hard red spring wheat (HRSW) was initiated in 1997 by WSU scientists in collaboration with the grower and the Benton County Wheat Growers Association on the Doug Rowell farm located in the southern

portion of the Horse Heaven Hills (Schillinger et al., 2002). Long-term average precipitation at the site is 6.5 inches per year, or approximately 5 inches less annual precipitation than at the previously discussed Ralston site. The grower's wheat yields from the fallow system ranged from 3 to 41 bu ac⁻¹ and averaged 18 bu ac⁻¹.

Fallow operations consisted of primary spring tillage with a V-sweep implement or tandem disk followed by two rodweedings to control Russian thistle. Nitrogen fertilizer use was limited to no more than 25 lb N ac⁻¹, or none in the driest years. Winter wheat was sown in late August with a deep-furrow drill in two years when

seed zone moisture was adequate for germination, or if too dry (four years), with hoe drills after onset of rains in October or November. With continuous no-till, hard red spring wheat was sown in February or early March with the Cross-Slot drill. Nitrogen fertilizer was applied in accordance with the soil moisture content and to achieve maximum grain yields with 14% or higher protein content. Up to three herbicide applications were required for adequate control of downy brome and Russian thistle. The primary in-crop herbicide for Russian thistle control was 2,4-D.

Growing season precipitation measured from 1 August through 31 July was well above normal during the 1997 and 1998 harvest years at 9.4 and 7.9 inches, respectively. During 1999–2002 it was below normal, averaging 4.7 inches, or 1.8 inches per year less than the long-term annual average of 6.5 inches. A timely rain in May increased 2002 wheat yields above the drought levels of 2001.

Figure 4.11 shows that the yields of continuous no-till HRSW are less than one-half of the alternate year yields of soft white winter wheat except in 2000 when they are about two-thirds less. Because of four successive dry years the continuous no-till HRSW averaged only 8 bu ac⁻¹ during 1997–2002 compared with 18 bu ac⁻¹ for winter wheat in alternate years after fallow. A record yield of over 41 bu ac⁻¹ in 1998 boosted the average for fallow considerably and is well above the long-term average for the Rowell farm. Protein content of HRSW was well below 14% in the first two years and above that in the remaining four driest years. The 6-yr average of the spring wheat yields when doubled is about 9% less than that of alternate year winter wheat. During the driest years, yields of the no-till systems were crop failures, which was also the case for winter wheat in 1999, 2001 and 2002.

Table 4.7 shows that gross returns for 1997–2002 averaged approximately \$2 per acre less for the hard red spring wheat compared with winter wheat-fallow (Young, 2002). However, the 6-yr average of total costs of the spring wheat system was 100% higher (\$72.79 versus \$36.30) than for the winter wheat system modeled after Doug Rowell's practices.

Young et al. (2001a) considered Rowell's practices to be among the lowest costs for winter wheat production anywhere in the US. Fallow tillage costs are reduced by using

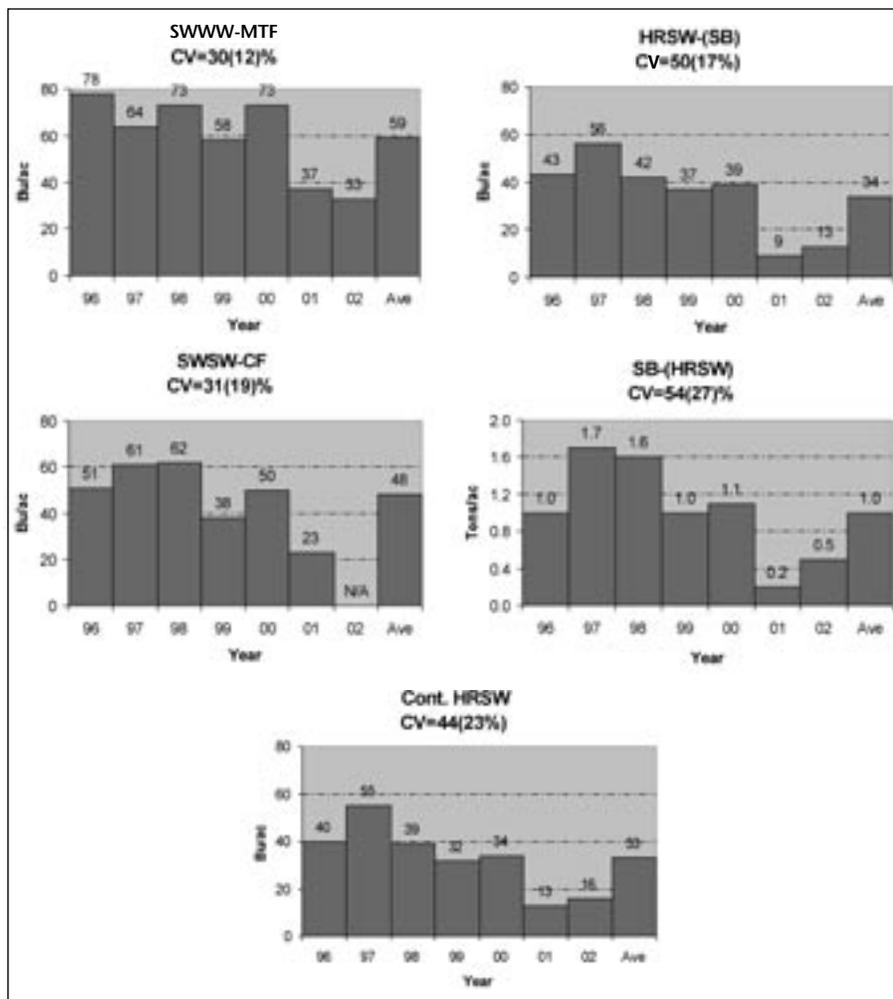


FIGURE 4.10. Comparisons of annual and average grain yields and CVs of continuous no-till spring cropping systems with minimum tillage winter wheat-fallow during 1996–2002 at the Ralston, WA field site. SWWW-MTF = soft white winter wheat–minimum tillage fallow; SWSW-CF = soft white spring wheat–chemical fallow; Cont. HRSW = continuous hard red spring wheat; and HRSW-SB is hard red spring wheat in rotation with spring barley and SB-HRSW is the same but alternate rotation. CV = coefficient of variation of the yields for 1996–2002 (except for SWSW-CF where it is for 1996–2001) and the number in parenthesis is the CV for 1996–2000. Source: Young (2001) and Young and Pan (2002).

machinery acquired and maintained at minimal cost, treating farm grain for seed, applying no fertilizer in the drier years, and limiting chemical weed control to the less expensive 2,4-D. The annual costs of the hard red spring wheat system that include regular use of fertilizer and herbicides, no-till sowing, and annual harvesting are double those for the winter wheat-fallow system. The end result is that over the six years of this study, 1997-2002, the continuous no-till hard red spring wheat system lost an average of \$44 ac⁻¹ yr⁻¹ while the grower's system lost \$6 ac⁻¹ yr⁻¹ (Table 4.7).

According to Young (2002) government payments might add another \$10 per acre per year for both cropping systems that would show a profit for SWWW-F but not for HRSW. In the budgeting technique total costs consisted of fixed and variable costs of crop production. Fixed costs included depreciation, interest, taxes, housing and insurance on machinery, and land rent. Variable costs included seed, fertilizer, herbicides, crop insurance, fuel, repairs and the operator's labor.

SUMMARY OF PERFORMANCE OF CONTINUOUS NO-TILL HRSW AND SWWW-F IN THE HORSE HEAVEN HILLS

The most significant findings and observations of the six-yr study in the Horse Heaven Hills, under the driest conditions of the Columbia Plateau are:

1. The profitability of continuous no-till HRSW cropping that provides the best possible protection against wind erosion was significantly lower than the traditional SWWW-F rotation. Winter wheat-fallow without government support payments averaged a loss of \$6 ac⁻¹ yr⁻¹ in net returns over all costs including the grower's labor, land and machinery investment whereas the no-till spring wheat system lost \$44 ac⁻¹ yr⁻¹.
2. The difference in profitability between the winter wheat-fallow and continuous hard red spring wheat systems was attributed to lower gross returns and the doubling of production costs with no-till high protein spring wheat.
3. The results of this experiment comparing the profitability of continuous no-till hard red spring wheat and winter wheat-fallow in the Horse Heaven Hills are similar to those obtained at the Ralston field study site (1995-2000) which receives about 5 inches more

annual precipitation than the Horse Heaven Hills site (discussed in more detail later).

4. Ponded water infiltration measurements in 2001 and 2002 after five and six years of treatment showed that there were no differences in water intake by soil in winter wheat stubble of the fallow rotation and continuous no-till hard red spring wheat stubble. However, soil penetrometer resistance was significantly greater in the surface nine inches of the no-till spring wheat treatment compared with winter wheat-fallow indicating that more soil compaction had occurred in the continuous no-till HRSW system (Schillinger, 2001b; Schillinger et al., 2002).
5. While winter wheat-fallow far exceeded no-till HRSW in profitability, the potential environmental benefits of the latter should encourage additional research to reduce production costs and increase yields of the continuous spring wheat system through plant breeding, pest control, and dryland water and nutrient management.
6. Chemical summer fallow should be evaluated as a replacement for tilled fallow, especially since farmers in the Horse Heaven Hills have carryover seed-zone water for early (August) planting of winter wheat only about 50% of the time. Some newly developed soil-residual broadleaf herbicides have shown excellent and extended control of Russian thistle in chemical fallow. Chemical fallow would be acceptable to many growers in the Horse Heaven Hills if government farm programs helped to offset the cost of herbicides and the possible reduction in yield due to delayed planting compared with tilled fallow. The practice would be a major step towards controlling wind erosion in the Horse Heaven Hills.

DROUGHT EFFECTS ON THE ECONOMIC RISK OF CONTINUOUS NO-TILL SPRING CROPS COMPARED WITH WINTER WHEAT-FALLOW IN ADAMS (RALSTON) AND BENTON (HORSE HEAVEN HILLS) COUNTIES

Yields of both spring cereals and winter wheat at the Ralston study site were favored by normal or above

precipitation in 1996-2000 and at the normally very dry Horse Heaven Hills site in 1997-98. Yields were reduced by considerably drier conditions in 1999 at the Horse Heaven Hills site, and especially so by droughts at both sites in 2001 and 2002.

Continuous hard red spring wheat, hard red spring wheat after barley and barley after hard red spring wheat at the Ralston site suffered yield reductions of 67, 79, and 84%, and 60, 70, and 64% in 2001 and 2002, respectively, compared with their 1996-2000 averages. However, reductions for winter wheat after fallow and soft white spring wheat after fallow were 46 and 56%, respectively for 2001, and 52% for winter wheat after fallow in 2002.

Yield risk as measured by the statistical coefficient of variation increased dramatically for all rotations when grain yields for 2001 and 2002 were included in the long-term averages, and was highest for the spring crops (Table 4.8; Young, 2002). The CV is a measure of variation in annual yields from their long-term averages. Greater departures from the average indicate less assurance in predicting future yields for a given system. Table 4.8 shows that the CV for the winter wheat-fallow rotation at Ralston increased from 12% for the 1996-2000 average yield to 23 and 30% for the 1996-2001 and 1996-2002 yields, respectively, and for the soft white spring wheat-chemical fallow rotation from 19% for the 1996-2000 yield to 31% for the 1996-2001 yield. With few exceptions, these CVs are considerably lower than for the continuous no-till spring cereals that increased from a range of 17 to 27% for 1996-2000 yields to 38 to 49% for 1996-2001, and 44 to 54% for 1996-2002 average yields (Table 4.8).

The effect of the 2001 and 2002 droughts on crop yields was more severe in the Horse Heaven Hills than at Ralston. Yield reductions in 2001 were 90 and 94% for winter wheat after conventional fallow and continuous no-till hard red spring wheat, respectively, compared with their 1997-2000 averages, and 64 and 46%, respectively, in 2002 compared with their 1997-2000 averages (Young, 2002). The coefficient of variation for winter wheat-fallow increased from 57% in 1997-2000 to 78 and 81% for the 1997-2001 and 1997-2002 yields, respectively, and for continuous spring wheat from 63% in 1997-2000 to 85 and 82% for the 1997-2001 and 1997-2002 yields, respectively (Table

4.8). The comparison of CVs for winter wheat after fallow is 23 and 78% in the 2001 average, and 30 and 81% in the 2002 average for the Ralston and Horse Heaven Hills sites, respectively. In the same order for continuous no-till hard red spring wheat they are 38 and 85% for 2001 and 44 and 82% for the 2002 yield averages.

It is noted that the starting year for the yield averages for the two sites differ by one year, i.e., at Ralston it was 1996 and at the Horse Heaven Hills site

it was 1997. Nevertheless, it is readily apparent that the yield risks with all rotations in the drier Horse Heaven Hills climate are considerably greater than at Ralston where average annual precipitation is about 77% higher.

The CVs in the Horse Heaven Hills through 2001-02 for winter wheat after fallow at 78 and 81% and continuous hard red spring wheat at 85 and 82% are very similar. At Ralston they are comparatively lower and differ more, with winter wheat at 23

and 30% and continuous hard red spring wheat at 38 and 44% for 2001 and 2002, respectively.

On the basis of net returns over total costs the average values for the Ralston experiment for 1996-2002 were $-\$49 \text{ ac}^{-1} \text{ yr}^{-1}$ for continuous no-till hard red spring wheat compared with $\$4 \text{ ac}^{-1} \text{ yr}^{-1}$ for soft white winter wheat-fallow (Table 4.6). For the Horse Heaven Hills experiment for 1997-2002 the values were $-\$44 \text{ ac}^{-1} \text{ yr}^{-1}$ for continuous no-till hard red spring wheat and $-\$6 \text{ ac}^{-1} \text{ yr}^{-1}$ for soft white winter wheat-fallow (Table 4.7). Thus, the winter wheat-fallow rotations in the two different precipitation zones averaged higher profitability than the continuous hard red spring wheat and exhibited less annual risk at the higher precipitation Ralston site (Table 4.8).

Table 4.6. Average net returns over total costs by rotation for 1996-2000, and 1996-2002 at Ralston, WA.^{1,6}

Rotation	Year	
	1996-2000	1996-2002
	-----\$/rot. ac-----	
SWWW-MTF²	16.29	3.81
SWSW-CF³	-11.99	NA
Cont. HRSW⁴	-25.55	-49.36
HRSW-SB⁵	-13.73	-38.11

¹Source: Young (2001, 2002), and Young and Pan (2002). Net returns assume yields with typical moisture and chaff levels for marketed grain.

²Soft white winter wheat-minimum tillage fallow (using average price of $\$3.44 \text{ bu}^{-1}$).

³Soft white spring wheat-chemical fallow. The treatment was discontinued after 2001.

⁴Continuous no-till hard red spring wheat (using average price of $\$4.18 \text{ bu}^{-1}$ plus adjustments based on actual protein).

⁵Continuous no-till hard red spring wheat-spring barley (using average price of $\$114.84 \text{ t}^{-1}$ for barley).

⁶Net returns for all periods include estimated government payments of $\$29 \text{ ac}^{-1} \text{ yr}^{-1}$.

Table 4.7. Comparison of annual costs and market returns for continuous no-till hard red spring wheat (HRSW) and soft white winter wheat-conventional fallow (WW-F) yields in the Horse Heaven Hills¹.

Year	Rotation	Gross returns	Total costs	Net returns ²
		-----\$/rotational ac-----		
1997	WW-F	45.58	39.51	6.07
	HRSW	40.00	83.61	-43.61
1998	WW-F	70.86	54.82	16.04
	HRSW	63.90	88.53	-24.63
1999	WW-F	14.62	29.81	-15.19
	HRSW	16.18	69.94	-53.76
2000	WW-F	34.06	33.90	0.16
	HRSW	24.66	62.88	-38.22
2001	WW-F	4.09	26.79	-22.70
	HRSW	2.80	62.59	-59.79
2002	WW-F	14.79	32.97	-18.18
	HRSW	23.87	69.18	-45.31
Ave	WW-F	30.67	36.30	-5.73
	HRSW	28.56	72.79	-44.22

¹Source: Young (2002).

²Includes only market returns excluding government payments.

CONTINUOUS NO-TILL WITH ALTERNATIVE SPRING CROP ROTATIONS

Cereals have long dominated dry-land cropping systems because of their greater adaptability to the soils and climate of the low precipitation zones compared with other crops. Moreover, winter wheat-fallow is in a dominant position because of its demonstrated economic advantages over annual spring cereal cropping. Thus, if spring cropping systems are to compete with winter wheat-fallow on the Columbia Plateau there is a need for alternative cropping systems that offer equal or greater economic return. In addition to erosion control, there are apparent advantages with longer rotations and in diversifying crops with respect to pest control, water and nutrient management, farm economics, and risk management, all of which are critical in developing profitable no-till spring cropping systems in a dry-land environment.

A study initiated in 1997 was conducted to evaluate the relative performance of three cereal-based, continuous no-till annual spring cropping systems with reference to: 1) soil moisture dynamics and crop yields, 2) root disease, weed shifts and weed ecology, 3) physical and biological properties of the surface soil, and 4) the economic potential of no-till annual spring cropping in lieu of the traditional winter wheat-fallow system (Schillinger 1999, 2000). The spring cropping systems were: 1) a 4-yr safflower (*Carthamus tinctorius* L.)-yellow mustard-wheat-wheat rotation, 2) a 2-yr wheat-barley rotation, and 3)

continuous wheat. All wheat was the soft white market class.

The experiment was conducted at two sites: from 1997-2001 in Adams County, WA on the Ron Jirava farm on deep Ritzville silt loam soil (average annual precipitation of 11.5 inches) and the other from 1997-2000 in Douglas County, WA on the Brad Wetli farm on shallow (2.5-foot deep) Touhey loam soil (average annual precipitation 10.5 inches). All phases of the rotations were sown each year with a no-till drill delivering seed and fertilizer in one pass. A Flexi-coil 6000 drill was used in 1997-99 at the Adams County site and a Cross-Slot no-till drill was used all years at the Douglas County site, and in Adams County beginning in 2000. Fertilizer (N, P, S) rates were determined on the basis of soil tests and moisture availability for maximum yield. Recommended herbicides were applied for weed control.

Neither experimental site included a winter wheat-fallow treatment, the dominant rotation practiced by growers in both areas. A grain yield and economic comparison with the traditional winter wheat-fallow production system was accomplished in Adams County by conducting a survey during 1997-2001 of neighboring farms that provided a sample size of 12 fields all within a five-mile radius of the experimental site having similar soils and climatic conditions (Juergens et al., 2003). The sample yields were divided into top, middle and lower thirds to enable comparisons of ranges with those of the spring crops.

Table 4.9 summarizes the crop yield data for five years, 1997-2001 at

the Adams County site and four years, 1997-2000 at the Douglas County site. After the fourth year safflower was discontinued in Adams County and the 2001 yield is estimated from its relationship with that of yellow mustard in the experiment. Table 4.9 shows that crop year precipitation ranged from a high of 20.3 inches in 1997 to lows of 7.9 to 8.0 inches in 1999-2001 but maintained a 5-yr average of 11.3 inches that is equivalent to the long-term average of 11.5 inches. All crops produced exceptionally high yields in 1997; however, the impact of drought was most severe in 2001 following three years of below normal precipitation.

In 2001, spring wheat following oilseeds in the 4-yr rotation were essentially crop failures yielding only 8 and 6 bu ac⁻¹, and barley and mustard yields were reduced by 85 and 76%, respectively, from their highs in 1997. Safflower appeared to be least affected by drought and had the lowest yield variation of all spring crops with a standard deviation of 38% of the 5-yr average yield (calculated from Table 4.9). Yellow mustard had the highest yield variation (standard deviation 94% of the average yield) compared with the standard deviation of the cereals in the annual spring crop rotations ranging between 50 and 62% of the 5-yr average yields.

Yield of winter wheat after fallow from the survey study was also highest in 1997 at 72 bu ac⁻¹ and lowest in 2001 at 36 bu ac⁻¹ with a 5-yr average of 57 bu ac⁻¹, and a relatively low standard deviation of 15 bu ac⁻¹ or 26% of the average yield (Table 4.9). Five-year

average yields of winter wheat for the sampled farms ranged from 50 to 68 bu ac⁻¹ (not shown). The variation was due primarily to differences in management (Young, 2002). Dividing the sample yields into top, middle, and bottom thirds gave average yields of 66, 56, and 49 bu ac⁻¹ with standard deviations that ranged from 13 to 15 bu ac⁻¹ (Young, 2002).

Precipitation at the Douglas County site was above normal or normal three of the four years of the experiment and below normal in 2000 with a 4-yr average about the same as the 5-yr average for the Adams County site (Table 4.9), and about one inch higher than the long-term average. However, the yields of oilseed crops were half or less (exceptions were safflower in 2000 and yellow mustard in 1999) in Douglas County compared with those in Adams County. Similarly, the yields of spring cereals in Douglas County ranged from one-third to two-thirds of those in Adams County. The poorer performance of crops in Douglas County was possibly due to lower spring temperatures and shallow soils typical of that particular area (Schillinger, 2000).

Table 4.10 summarizes the net returns over total costs for each rotation in the Adams County study. Reporting results in dollars per rotational acre provides a common unit of measurement and permits comparisons of average profitability across rotations. The results show that of the spring crop rotations, continuous no-till soft white spring wheat (SW) had the highest average net return at \$4.90 ac⁻¹ followed by the 2-yr SW-SB and 4-yr S-YM-SW-SW at -\$4.90 and -\$12.73 ac⁻¹, respectively. The 5-yr return of continuous SW was statistically equivalent to that of SWWW-F at \$8.71 ac⁻¹ and is the first known result where a continuous no-till spring cropping system over years has proven to be as profitable as traditional winter wheat-fallow on the Columbia Plateau drylands (Fig. 4.12).

Soft white wheat and feed barley prices used in this analysis were \$4.08 bu⁻¹, and \$102.16 ton⁻¹, respectively which are regional averages for 1997-2001 farm gate prices (converted from Juergens et al., 2003). The average contract price of \$0.15 lb⁻¹ that growers received during this period was used for safflower and yellow mustard. Net returns excluded government and crop insurance payments because the study was intended to rank the market profitability of different rotations rather than farm income.

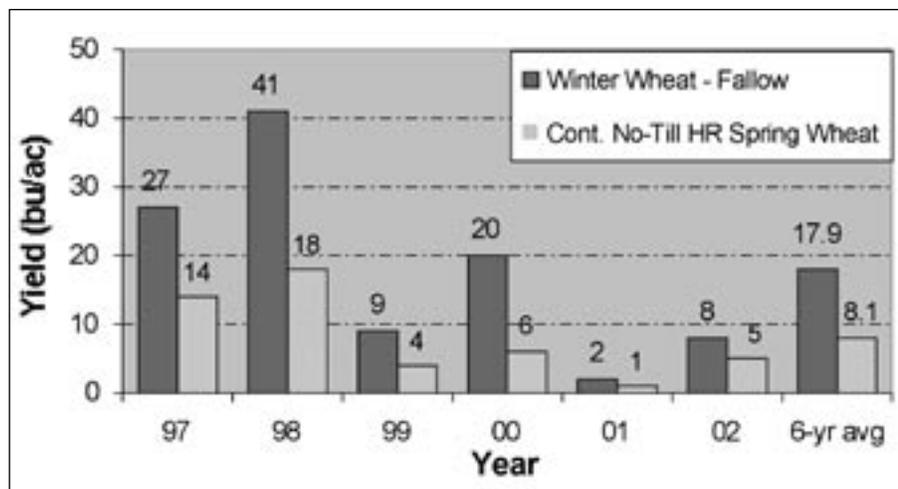


FIGURE 4.11. Grain yields of soft white winter wheat-fallow compared with continuous no-till hard red spring wheat in the Horse Heaven Hills of south central Washington during 1997-2002. Source: Schillinger (2002).

The standard deviations of net returns over total costs indicate that the winter wheat–fallow rotation was the least risky of the rotations with a standard deviation of \$14.96 followed by S–YM–SW–SW at \$36.70, continuous SW at \$40.86 and SW–SB at \$41.69 (Table 4.10). Yield depressions from low moisture conditions are the main cause of decreased profitability and increased risk with spring cropping in 1999 and 2001. Yields of winter wheat–fallow fluctuated to a lesser extent.

The severe drought of the 2001 crop year reduced the yield of spring wheat at the Adams County site from previous 4-yr averages by 85, and 73% following the broadleaf oilseeds and spring barley crops, respectively, and by 68% in the continuous spring wheat system. Likewise spring barley yield following spring wheat was about 75% less than the previous 4-yr average.

SUMMARY OF RESULTS FROM FIELD TRIALS OF CONTINUOUS NO-TILL SPRING CROP ROTATIONS IN ADAMS AND DOUGLAS COUNTIES, WA

1. In Adams County, continuous no-till soft white spring wheat yields were similar for the first year following mustard, after barley, and continuous wheat. The second year wheat after mustard in 2000 yielded 38 bu ac⁻¹, 6 bu ac⁻¹ less than wheat after barley at 44 bu ac⁻¹, and 5 bu ac⁻¹ less than continuous spring wheat at 43 bu ac⁻¹(Table 4.9). Less available water following two years of oilseed crops may have been offset in the first year crop by a possible beneficial “rotation effect” from these broadleaf crops which then declined with time. Overall, barley yields compared well with neighboring grower fields but were unusually low in 1999 due to low spring rainfall and a May frost.
2. Plant stand establishment of safflower and mustard was marginal in 1997-1999 when sowed with a Flexi-Coil 6000 no-till drill but was markedly improved in 2000 when sown with a Cross-Slot drill (Schillinger, 2000). Yellow mustard was produced successfully in only one of the five years (1997); it was injured by frost in 1999 and yields of both broadleaf crops were below optimum in 2000 due to heavy infestation of Russian thistle.
3. In Douglas County, spring wheat yields showed little or no response

to any of the treatments, and yields in 2000 were considerably lower than in previous years (Table 4.9). Safflower and yellow mustard did not produce successfully in any year possibly due to cool temperatures and shallow soil. Stands were adequate in all years except for yellow mustard in 2000 likely due to a dry seed zone in the top one-inch of soil. Barley yields were marginal and extremely low in 1999 and 2000 (Table 4.9).

4. Severe infection of wheat and barley with *Rhizoctonia* root rot first appeared in 1999 (third year of the study) at the Adams county site and has continued to spread as evidenced by larger and more numerous bare patches with the highest infestation to date in the 2002 crops. Land area affected by the disease increased from 5.4% in 1999 to 8.4% in 2000, and to 11.5% in 2002. Previous crop history including two years of broadleaf crops has had no significant effect on the level of *Rhizoctonia* infection in wheat (Cook et al., 2002). Despite this disease, continuous soft white spring wheat has remained profitable.
5. Russian thistle was the dominant weed at both sites but was especially troublesome in safflower and yellow mustard because no labeled in-crop herbicides are available for its control. Though present, Russian thistle can be readily con-

trolled in spring cereals with available herbicides. Mare’s tail, prickly lettuce and tansy mustard (*Descurainia richardsonii* var. *sonnei*) also infested safflower and yellow mustard but these weeds can be controlled with herbicides when the rotation changes to wheat.

6. Safflower and yellow mustard extract up to two inches more water from the soil than spring wheat leaving a deficit in the profile that can decrease yields of the following cereal crops for two or more years. Soil water recharge in the winter following safflower and yellow mustard is generally less than for wheat or barley presumably because the broadleaf crops leave less surface residue cover (Fig. 4.13).
7. Continuous soft white wheat was the only one of three no-till spring cropping systems to average positive net returns over total costs at \$4.90 over five years. The cropping system was the first on the Columbia Plateau drylands shown to be economically-competitive with the traditional winter wheat–fallow system with a statistically equal average net return over total costs of \$8.71 ac⁻¹ over five years. However, the profit risk level of winter wheat–fallow was considerably lower than the continuous spring cropping systems (Table 4.10).
8. The 4-year rotation of safflower–yellow mustard–spring wheat–

Table 4.8. Yield risk as coefficient of variation of crop yields for three periods at the Ralston and Horse Heaven Hills experimental sites comparing wheat–fallow with continuous no-till spring cropping systems¹.

Location and Rotation	Yield risk (CV%)		
	-----Year-----		
	1996-2000	1996-2001	1996-2002
Ralston			
SWWW–F²	12	23	30
SWSW–CF³	19	31	NA ⁶
Cont. HRSW⁴	23	38	44
HRSW–SB⁵	17	41	50
SB–HRSW	27	49	54
Horse Heaven Hills	1997-2000	1997-2001	1997-2002
SWWW–F	57	78	81
Cont. HRSW	63	85	82

¹Source: Young (2001, 2002).
²Soft white winter wheat–fallow.
³Soft white spring wheat–chemical fallow
⁴Continuous no-till hard red spring wheat.
⁵Hard red spring wheat–spring barley.
⁶Treatment was discontinued after 2001.

spring wheat was the least profitable of the spring crop systems with a loss of \$12.73 ac⁻¹ over five years. The rotation produced negative net returns in all years except 1997, i.e., before rotational effects may have occurred. However, the rotation had the lowest profit risk level of the spring cropping systems with a standard deviation of \$36.70 compared with \$41.69 and \$40.86 for the spring wheat–spring barley and continuous spring wheat systems, respectively.

9. During the drought of 2001 net returns from the spring cropping systems were lowest for the spring wheat–barley rotation (–\$56.97 ac⁻¹) and highest from the 4-yr oilseed rotation (–\$41.92 ac⁻¹). The

effects of drought in 1999 and 2001 significantly reduced the average profitability and increased the economic risk for the three spring crop rotations.

GROWER EXPERIENCE AND NEW DIRECTIONS IN RESEARCH WITH ALTERNATIVE CROPPING SYSTEMS IN ADAMS COUNTY, WA

To complement the alternative cropping systems study in Adams County, the cost of producing several continuous no-till spring crops by grower cooperator, Ron Jirava, were estimated for 1997-99 (Juergens et al., 2002). The crops were the same as in the experimental 4-yr rotation, i.e., safflower, yellow mustard, spring barley, and spring wheat. Spring wheat was grown in a continuous system,

and the oilseeds, barley and some spring wheat were grown in rotations similar to the Adams County experiment but operating costs were calculated on a per crop basis.

Table 4.11 shows average 3-yr prices, crop yields, total costs, net returns over total costs and the individual “break-even yields” for safflower, yellow mustard and barley, and continuous no-till soft white spring wheat. Total costs include a return for the operator’s labor and investment in land and machinery, and the variable production costs of fuel, seed, repairs and chemicals. Government farm payments are excluded as a revenue item. The break-even yield is the necessary yield to produce a zero return over total costs at the prices received. The prices for wheat and barley in Table 4.11 are marketing year averages for Washington. For the oilseeds, it is the contract price received by the grower.

Averaged over three years, continuous no-till soft white spring wheat with \$12.86 net returns over total costs was by far the most profitable crop. All other crops returned negative profits. At market prices, yields of yellow mustard, safflower, and barley would need to be increased on the average by 19, 10, and 4%, respectively, to exactly cover total costs. Alternatively, a price increase of \$2.74 t⁻¹ for barley, \$0.01 lb⁻¹ for safflower and \$0.03 lb⁻¹ for yellow mustard for the yields produced would enable the grower to break even.

The years 1997-99 received more precipitation than 2000-01 and produced average or above average crop yields. Nevertheless, the grower’s experience corroborates the agronomic and economic results obtained in the Adams County field experiment (Juergens et al., 2003; Schillinger, 2002).

After five years (in 2001) the experimental design of the original Adams County experiment reported by Juergens et al. (2003) was changed to include some new rotations and crops, all no-till. The rotations are those listed in Table 4.5 and have been discussed. The 2-year soft white spring wheat–spring barley rotation, and the continuous soft white spring wheat system were continued from the original experiment that began in 1997 (Schillinger, 2001b).

Table 4.9 Crop yields for alternative crop rotations in Adams (1997-2001) and Douglas (1997-2000) Counties, WA.

Location, rotation, and crop	Year					Ave	S.D. ¹
	1997	1998	1999	2000	2001		
Adams Co.²							
4-yr							
S³ (lb ac⁻¹)	1420	720	1040	600	702 ⁴	896	336
YM (lb ac⁻¹)	1430	340	110	490	350	544	514
SW (bu ac⁻¹)	64	41	27	40	8	36	21
SW (bu ac⁻¹)	58	37	25	38	6	33	19
2-yr							
SW (bu ac⁻¹)	65	40	28	44	12	38	20
SB (t ac⁻¹)	2.30	1.13	0.76	1.30	0.35	1.17	0.73
Cont. SW (bu ac⁻¹)	64	41	27	43	14	38	19
SWWW-F (bu ac⁻¹)	72	58	59	61	36	57	15
Precipitation (in)⁵	20.3	11.1	7.9	9.1	8.0	11.3	5.1
Douglas Co.⁶							
4-yr							
S (lb ac⁻¹)	630	340	420	529	NA	480	NA
YM (lb ac⁻¹)	410	140	330	78	NA	240	NA
SW (bu ac⁻¹)	NA ⁷	28	18	12	NA	19	NA
SW (bu ac⁻¹)	NA	NA	16	13	NA	5	NA
2-yr							
SW (bu ac⁻¹)	NA	26	21	13	NA	20	NA
SB (t ac⁻¹)	1.20	1.00	0.35	0.52	NA	0.77	NA
Cont. SW (bu ac⁻¹)	19	26	18	12	NA	19	NA
Precipitation (in)	12.6	14.3	10.5	7.9	NA	11.3	2.8

¹Standard deviation.

²Adapted from Juergens et al. (2003).

³S = safflower, YM = yellow mustard, SW = soft white spring wheat, SB = spring barley, Cont. SW = continuous soft white spring wheat and, SWWW-F = soft white winter wheat–fallow.

⁴Safflower was discontinued in 2001; the yield was estimated from its historical relationship following yellow mustard.

⁵Crop year (September 1–August 31).

⁶Adapted from Schillinger (2000). All crops in 1997, the first year of the study, were sown into spring wheat stubble. Wheat yields among treatments were not significantly different at the 5% level of probability in 1998-2000.

⁷Not available, or computed.

CONTINUOUS NO-TILL ANNUAL DRYLAND CROPPING SYSTEMS AT THE LIND RESEARCH STATION

A long-term experiment was initiated in 1998 at the WSU Dryland Research Station at Lind, WA to evaluate the agronomic performance of several rotations of annual crops in a continuous no-till system. Cropping systems are: 1) a 4-yr safflower–oat–spring wheat–spring wheat rotation, 2) a 2-yr winter wheat–spring wheat rotation, and 3) continuous spring wheat.

All spring wheat was soft white and all crops were sown with a Cross-Slot drill in 8-inch rows in 500-ft long plots. Average annual precipitation for the first four crop years was 9.24 inches [range 9.86 (1999) to 8.30 (2001)] compared with the 80-year average of 9.61 inches. Drought was severe in 2001 and reduced yields of all crops on non-fallow land in the dryland areas. In addition, recrop winter wheat in the rotation with spring wheat was injured by a late May frost in 2001 and yielded only 13 bu ac⁻¹. Results of crop yields through 2001 are presented in Table 4.12.

Some of the key findings and observations of the research are as follows:

1. Safflower produced relatively stable yields averaging 799 lb ac⁻¹ over four years. With production costs at \$108.53 ac⁻¹ and a market price of \$0.12 lb⁻¹ the crop would generate an average net return of -\$13.00 ac⁻¹ (Juergens et al., 2002). Soil water measurements indicate that safflower extracts much more water than cereals which can be detrimental to the crops

that follow in an annual dryland cropping system. In view of this and other research, considering its pattern of water use, its poor economic performance, and lack of apparent rotational benefits, there appears to be little advantage to growers in producing safflower.

2. Over a 4-year cycle at Lind, WA, the yield of continuous no-till soft white spring wheat averaged only 50% of that for winter wheat after fallow. The yield ratio of spring wheat:winter wheat ranged from 0.30 to 0.55 during 1998-2002. However, the economic competitiveness of continuous no-till, soft white spring wheat, or in rotation with conservation tillage winter wheat–fallow, needs additional study over years and under different environmental conditions.
3. Oat following safflower averaged 0.85 t ac⁻¹ during 1998-2000 and 0.64 t ac⁻¹ when the low yield of the 2001 drought year was included.
4. The feasibility of recrop winter wheat in rotation with spring wheat merits continued evaluation.

MANAGING RUSSIAN THISTLE IN DRYLAND CROPPING SYSTEMS

Russian thistle is a summer annual weed that presents a formidable obstacle to successful dryland spring cropping (Fig. 4.14; Young, 1987; Schillinger and Young, 2000). It is suppressed in uniform and healthy

stands of winter wheat but grows vigorously where crop competition is limited by poor stands, drought, inadequate fertility and late growth (Young, 1986; Young et al., 1995). Under these conditions it competes mainly through development of an aggressive root system (Pan et al., 2001). Spring crops, and late-planted or poor stands of winter wheat are especially vulnerable to weed infestations because of less early growth and slower canopy closure compared with early fall-planted winter wheat. These crops are also most often associated with low crop residue production.

Growers are advised to strive for maximum control of Russian thistle in crop management as a way to maintain and increase crop residue production for erosion control (Young et al., 1995). Its use of soil water and nutrients can seriously reduce crop yields if allowed to infest fields above threshold levels. Up to 55% of spring wheat yield loss as well as fields in an unharvestable condition may occur with heavy infestations of Russian thistle (F. Young, USDA Agricultural Research Service, Pullman, WA, personal communication, July, 2003). However, residue from weeds that have escaped control measures should be managed as a supplemental source of surface cover for wind erosion control, especially where crop residues are severely limited (Schillinger et al., 1999b).

SOIL WATER USE, AND DRY MATTER AND SEED PRODUCTION BY RUSSIAN THISTLE

Schillinger and Young (2000) showed that individual Russian thistle plants growing in a grid, one plant every 387 ft², extracted on the average 18.6 gal of soil water while growing in the crop, and additional 27 gal after wheat harvest in early August until killed by frost in late October. Most of the water use occurred within a 5 ft radius (80 ft² area) of the plant, and to depths of 4.5 to 6 ft. The 45 gal of total water use amounts to 0.92 inch of soil water from the extraction radius of each thistle plant. With thistle plants spaced 10 ft apart in a grid over a field this loss of water would reduce the yield potential of the next wheat crop by approximately 5 bu ac⁻¹.

The 2-yr average dry biomass of individual Russian thistle plants in the 10-ft grid was about 0.4 lb just after spring wheat harvest with an additional 2.4 lb produced until killing frost in October for a final dry

Table 4.10. Net returns over total costs for three experimental continuous no-till spring crop rotations compared with grower returns from local winter wheat–fallow in Adams County, 1997-2001¹.

Rotation ²	Year-----					Ave	S.D.
	1997	1998	1999	2000	2001		
	-----\$ per rotational acre-----						
4-yr							
S-YM-SW-SW	50.29	-14.96	-33.97	-23.08	-41.92 ³	-12.73a ⁴	36.70
2-yr							
SW/SB	57.40	2.41	-22.44	-4.88	-56.97	-4.90ab	41.69
Cont. SW	63.41	17.41	-14.75	5.60	-47.16	4.90b	0.86
SWWW-F	26.11	9.61	9.91	13.11	-15.19	8.71	14.96

¹Adapted from Juergens et al. (2003).

²S = safflower, YM = yellow mustard, SW = soft white spring wheat, SB = spring barley, Cont. SW = continuous soft white spring wheat, and SWWW-F = soft white winter wheat–fallow.

³The 2001 net return for safflower is estimated using its historical yield relationship following yellow mustard.

⁴Average net returns followed by the same letter are not significantly different. The LSD_{0.05} for the three experimental rotations is \$12.32 ac⁻¹.

weight of 2.8 lb. With thistle plants uniformly spaced approximately 10 ft apart this calculates to a mass of 1,435 lb of residue ac^{-1} , a value that agrees with that measured in spring wheat experiments by Schillinger et al. (1999b).

Experiments showed that although the larger Russian thistle plants begin to produce seed in August, appreciable numbers of germinable seeds were not produced until near mid September. From then on, percent germination continued to increase to a maximum of 48% after which the plants were killed by frost in late October (Schillinger and Young, 2000). Russian thistle is an

indeterminate plant that ceases growth and seed production when the temperature drops to 25 °F for one night or just below 32 °F for several nights in a row (Young et al., 1995).

MANAGING RUSSIAN THISTLE IN LOW RESIDUE CONDITIONS

Killing weeds increases grain yield, and crop residue for wind erosion control and should be a high priority management criterion in any farming operation. Because of its persistence in the low precipitation areas, measures to control Russian thistle need to be compatible with requirements for effective wind erosion control

under dry cropping conditions. With low crop residue and Russian thistle infestation, Schillinger and Young (2000) recommend application of a burn-down herbicide or undercutter sweep operation 10 to 14 days after wheat harvest when the thistle begins rapid re-growth (Young, 1986). Both methods cease water use and seed production, but chemical control leaves the thistle plants intact. Cultivation is less expensive and minimizes weed escapes; however, it uproots the thistle plants enabling them to blow away and distribute seeds throughout fields. This increases the need for weed management in the following crop. Moreover, cultivation loosens the soil and reduces surface cover that further increases the wind erosion hazard.

In spring of the fallow cycle, the minimum tillage or delayed minimum tillage practice is recommended to maintain adequate surface cover for erosion control through the fallow period (Schillinger, 2001a). With minimum tillage fallow, Russian thistle skeletons from the previous crop year were sometimes sufficient to meet minimum cover requirements for wind erosion control in a relatively dry year whereas this was not achieved with traditional fallow tillage that included both crop and thistle residues (Schillinger et al., 1999b).

For extremely low crop residue conditions following spring wheat, Schillinger and Young (2000) recommend allowing the thistles to grow for a period of 5-7 weeks after crop harvest and then killing them to stop water use and seed production using a fast acting herbicide such as paraquat. During this time in an average season the weeds will have produced approximately 900 lb ac^{-1} of residue and consumed 0.4 inch of water that could reduce subsequent wheat yield by about 3 bu ac^{-1} . For fallow, the minimum tillage or delayed minimum tillage practices (Schillinger, 2001a) are recommended for the following spring.

Growers in the dry areas have basically two questions regarding the management of Russian thistle with winter wheat-fallow, i.e., 1) given the Russian thistle seed density throughout the dryland region and the relatively short life of the seeds in the soil (two to three years), does it even pay to control the weed after harvest?, and 2) using a V-sweep for post-harvest control of Russian thistle is less expensive than herbicides, but is over-winter water storage greater when sweeping is not done? (Schillinger, 2001b).

Table 4.11. Average yields, prices, costs, net returns and break-even yield for four crops produced by grower Ron Jirava during 1997-99 near Ritzville, WA.¹

Crop ²	Yield	Price	Total cost ³	Net Return ⁴	BEY ⁵
SW	41 bu ac^{-1}	\$3.17 bu^{-1}	116.03	12.86	37 bu ac^{-1}
SB	1.35 t ac^{-1}	\$77.91 t^{-1}	108.88	-3.71	1.4 t ac^{-1}
S	822 lb ac^{-1}	\$0.12 lb^{-1}	108.53	-9.88	904 lb ac^{-1}
YM	651 lb ac^{-1}	\$0.12 lb^{-1}	96.03	-17.87	775 lb ac^{-1}

¹Adapted from Juergens et al. (2002).

²SW = soft white spring wheat, SB = spring barley, S = safflower, and YM = yellow mustard.

³Includes variable cost plus a return for the operator's land and machinery investment.

⁴Over total cost.

⁵Break-even yield is the yield necessary to generate a zero return over total costs given the price received.



FIGURE 4.12. Adams County grower Ron Jirava kneeling in a large-scale experimental plot on his farm where soft white spring wheat has been grown under continuous no-till for seven consecutive years. This crop in 2003 produced 24 bu ac^{-1} with 10 inches of growing season precipitation compared to the 7-yr average yield of 33 bu ac^{-1} . The experiment produced the first results on the Columbia Plateau that show a continuous no-till annual cropping system to be as profitable as traditional soft white winter wheat-fallow. Continuous no-till soft white spring wheat over seven years made a positive profit compared with annual rotations of wheat, oilseeds and barley that all returned negative profits. Photograph by W.F. Schillinger. WSU.

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An experiment in its fifth year at the WSU Dryland Research Station at Lind, WA showed that controlling Russian thistle after harvest either with wide blade V- sweeps or with Surefire herbicide (paraquat + diuron) applied 7-10 days after wheat harvest significantly reduced Russian thistle water use at time of killing frost all years. This resulted in a significantly higher wheat yield one year compared with a check treatment with no con-

trol (Schillinger, 2002). Mechanical sweeping was more effective for post-harvest control than the burn-down herbicide during three of the five years because the tillage kills all of the weeds while some may recover from the contact herbicide treatment.

Controlling post-harvest Russian thistle seed production is especially important when spring cropping is planned in lieu of summer fallow (Young, 1987). For this, post-harvest

sweep tillage or herbicide applications are acceptable management options (Schillinger and Young, 2000). The spring crop should be sown in the carry-over residue early with minimum soil disturbance to maximize protection against wind erosion, and at close row spacing (10 inches or less) to increase the crop's competitiveness against Russian thistle.

SUMMARY OBSERVATIONS

Winter wheat-fallow, a traditional method of farming in the drylands of the Pacific Northwest, continues to be the dominant cropping system in the low precipitation zones. It is favored over most alternative systems because it is generally more profitable and involves less risk. With an intervening year of fallow, enough additional water is stored in the soil profile to ensure a harvestable crop most years, weeds can be controlled, and machinery and labor demands can be spread more uniformly throughout the year. The downside with traditional fallow is that intensive tillage to control weeds and conserve seed zone moisture leaves the soil smooth with little protective cover and highly susceptible to wind erosion for 6 to 8 mo every two years.

In most situations the maintenance of adequate crop residues and/or vegetative cover at the soil surface is the "key" element to controlling wind erosion of fallowed soils and minimizing the impairment of air quality on the Columbia Plateau and downwind areas. Consequently, scientists have taken two approaches in seeking ways to control wind erosion on dryland farms. First has been the development of conservation practices for the tilled winter wheat-fallow system, while the second has explored alternatives to tilled fallow such as controlling weeds mainly with herbicides (i.e., chemical fallow) and re- or flex-cropping in no-till systems with winter and spring crops. The overall objectives of the latter approach are 1) to provide year-round protective cover for no-till soils against wind erosion, and 2) to conserve and store additional precipitation to allow annual cropping even in relatively dry years, wherein the grower could resort to chemical fallow in drought years.

Minimum and delayed minimum tillage for fallow that required three to five tillage operations significantly increased surface residue and roughness compared with conventional tillage employing eight or more till-

Table 4.12. Grain yields in three continuous no-till crop rotations at Lind, WA, 1998-2001¹.

Rotation and crop ^{2,3}	Year				Ave
	1998	1999	2000	2001	
4-yr					
S (lb ac⁻¹)	890	775	1005	525	799
O (t ac⁻¹)	1.23	0.46	0.78	0.09	0.64
SW (bu ac⁻¹)	—	18	21b ⁴	8b	16
SW (bu ac⁻¹)	—	—	22b	9b	16
2-yr					
WW (bu ac⁻¹)	—	—	40a	13a	27
SW (bu ac⁻¹)	—	—	24b	9b	17
Cont. SW (bu ac⁻¹)	28	21	24b	15a	22

¹Adapted from Schillinger (2001b).

²All crops were sown into spring barley stubble in 1998, the first year of the study. The 2-yr rotation started in the 2000 crop year.

³S = safflower, O = oat, SW = soft white spring wheat, WW = soft white winter wheat, and Cont. SW = continuous soft white spring wheat.

⁴Within column means followed by a different letter indicate significant wheat grain yield differences at the 5% probability level.



FIGURE 4.13. Introduction of yellow mustard or safflower into cereal-based annual no-till dryland cropping systems did not improve their profitability or provide any rotational benefits such as pest control. The photograph illustrates that mustard is susceptible to *Rhizoctonia* bare patch disease as are other oilseeds and cereals. Moreover, the oilseed crops tend to use more soil water than cereals that can create a deficit for following crops. Under present circumstances it is probably more advantageous for dryland growers to plant continuous cereals in annual cropping systems. Photograph by W.F. Schillinger.

age operations. Moreover, these conservation practices also equaled the profitability of the conventional tillage winter wheat-fallow system that less frequently met minimum erosion control requirements. Simulations with the regional air quality model predicted that application of the minimum tillage fallow systems would reduce PM emissions by about 54% and continuous no-till cropping by about 95% compared with conventional tillage fallow.

Research with continuous no-till annual cropping systems with spring crops and occasionally winter wheat shows that although they perform well agronomically in years of normal and above normal precipitation, they are considerably less profitable than the soft white winter wheat-fallow system. One exception was a 7-yr experiment in an 11.5 inch precipitation zone where continuous no-till soft white spring wheat was equally profitable with soft white winter wheat-fallow. This is the first result in the Pacific Northwest showing that continuous no-till spring cropping can be economically competitive with the more erosion-prone winter wheat-fallow system. This result occurred despite limited moisture, and disease pressure from *Rhizoctonia* root rot in the annual cropping system.

Under most conditions there was a higher risk potential (greater yield variations and more severe effects of drought on yield) with the annual cropping systems compared with winter wheat-fallow except under extremely dry conditions where they were similar. Introduction of broadleaf oilseed crops into the cereal-based annual system did not improve farm profitability or provide any major rotational benefits such as pest control. Instead these crops tend to extract more water from the soil profile that creates a potential deficit for the following cereal crops. In this regard, it would probably be more advantageous for dryland growers to plant continuous cereals in annual cropping systems.

Surveys indicate public support for air quality improvements that can be achieved through conservation farming. Public cost sharing to reduce financial risk and aid start-up in the transition years would be an innovative possibility for encouraging more growers to adopt conservation systems. Another is to provide increased support for research in plant breeding, nutrient management, pest control and related technologies to

help ensure the profitability of annual cropping systems in the dryland areas. Opportunities for reducing production costs associated with continuous no-till annual cropping systems also need to be explored.

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FIGURE 4.14. Russian thistle infestations as in this field are a major obstacle to successful dryland spring cropping by competing with crops for soil water and nutrients. It grows vigorously where crop competition is limited by poor stands, drought, inadequate fertility and late growth, all of which result in low crop residue production. Although thistle skeletons when present should be managed for surface cover, growers are advised to strive for maximum control of Russian thistle in crop management with combinations of minimum tillage and herbicides, as a way to maintain and increase crop residue production for erosion control. Photograph by F.L. Young, USDA-ARS, Pullman, WA.

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