

## *Cropping Systems Research in the World's Driest Rainfed Wheat Region*

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### **ABSTRACT**

Winter wheat - summer fallow (WW-SF) is the predominant cropping system in the 300,000-acre Horse Heaven Hills (HHH) region in south-central Washington, USA. Blowing dust from residue- and roughness-deficient summer fallow results in soil loss and causes health problems. Annual no-till cropping to replace summer fallow would provide year-round protection against wind erosion. A 6-year field study conducted from 1996 to 2002 evaluated the agronomic and economic feasibility of continuous annual no-till hard red spring wheat (HRSW) as an alternative to traditional WW-SF. Long-term average annual precipitation at the experiment site is 6 inches, which we believe is the lowest for any nonirrigated wheat region of the world. Annual precipitation during the study ranged from 4.4 to 9.5 inches and averaged 6.0 inches when two wet years were followed by a 4-year drought. Russian thistle heavily infested HRSW plots and depleted soil water during the two wet years. Seed-zone water content in summer fallow was sufficient to plant WW in late August in only two of six years. Average (6-year) grain yield was 17.7 bu/acre for WW-SF (one crop every two years) and 7.9 bu/acre for annual no-till HRSW. The number of kernels per head had a significant contribution to yield during years of acute water stress. Net economic returns for annual HRSW lagged WW-SF by an average \$38 per acre per year. Although continuous annual no-till cropping has clear environmental advantages, it is not economically competitive with WW-SF given current technology in the Horse Heaven Hills.

**Abbreviations:** HHH, Horse Heaven Hills; HRSW, hard red spring wheat; PSE, precipitation storage efficiency; SF, summer fallow; WW, winter wheat.

### **INTRODUCTION**

Drought, tillage, low production of crop residue, nonaggregated soils with low organic matter content, and high winds often combine to leave soil vulnerable to wind erosion in the Horse Heaven Hills (HHH) region of south-central Washington. Winter wheat – summer fallow (WW-SF), where only one crop is produced every two years, is the dominant dryland crop rotation. Farmers in the HHH are considered some of the best practitioners of conservation tillage in the inland Pacific Northwest, but wind erosion from SF or newly planted WW fields is a major soil loss and air quality concern. Farmers practice the WW-SF rotation on 3.71 million acres in the low (<12 inch annual) precipitation region of eastern Washington and north-central Oregon—by far the largest dryland cropping zone in the western United States. Many farmers and others believe successful new cropping technologies developed for the HHH also may be applicable to the higher precipitation portions of the WW-SF region.

While annual spring crops are not typically grown in the HHH, they have the potential to markedly control wind erosion. One computer model estimated that annual no-till spring cropping would reduce predicted dust emissions by 94% during severe wind events compared with conventional WW-SF (Lee, 1998).

The main purpose of SF is to store a portion of over-winter precipitation to enable successful establishment of WW planted deep into moist soil in late August. Precipitation storage efficiency (PSE, the percentage of precipitation stored in the soil) during the year-long summer fallow period is 30% or lower (Leggett et al., 1974). About half the time, the seed zone (6 to 8 inches deep) is too dry for HHH farmers to plant WW in late August; thus they plant shallow (1 inch deep) into dry soil or delay planting until the onset of fall rains in late October or November. Planting in late October reduced straw and grain yields in a 10-inch annual precipitation zone by 60% and 30%, respectively,

compared with planting in late August deep into moist soil with 6 inches of soil covering the seed (Donaldson et al., 2001). These reductions seriously impact erosion potential and farm economics in the region. Papendick et al. (1973) explained the processes of water loss and seed-zone water retention from summer fallow under Pacific Northwest conditions.

Due to inefficient PSE, frequent difficulty with WW stand establishment from deep planting depths, and wind erosion hazard, farmers in the HHH are interested in alternatives to WW-SF. The purpose of our study was to compare the results of planting WW-SF and continuous annual no-till hard red spring wheat (HRSW) for grain yield, grain yield components, straw production, PSE during the noncrop period, and farm economics.

## MATERIALS AND METHODS

Researchers conducted a 6-year field experiment from 1996-2002 in the HHH region of Benton County, south-central Washington, to compare results of the traditional WW-SF rotation and continuous annual no-till HRSW. Annual long-term precipitation in the HHH ranges from 6.0 to 8.5 inches (Rasmussen, 1971). The experiment was designed in collaboration with an advisory committee of regional farmers. The farmers requested that the experiment site be located in the driest portion of the HHH cropping region, 12 miles due south of Prosser, WA, that receives only 6.0 inches of average annual precipitation. Pan evaporation (March to November) averages 40 inches. Land for the experiment was provided by farmer-cooperator, Doug Rowell.

Precipitation was recorded from July 1996 to July 2002 at the Washington State University Public Agricultural Weather Station (PAWS) located on the experiment site. Historic (20-year) WW grain yield (after fallow) on the farmer's field at the site ranged from 3.0 to 30 bu/acre and averaged 18 bu/acre.

The soil is a Warden very fine sandy loam formed in a thin mantle of loess over lacustrine sediments (Rasmussen, 1971). A thin-weak layer of calcium carbonate accumulation occurs at  $\approx 20$  inches, but otherwise no impermeable layers or rocks exist within the 6-foot profile. Slope was less than 2%.

## Treatments and Field Operations

There were two cropping system treatments: i) WW-SF, and ii) continuous annual HRSW. Both crop and summer fallow phases of the WW-SF rotation were present each year. Experimental design was a randomized complete block with six replications. Eighteen plots covered a total land area of 8.4 acres. Individual plot size was 300 feet by 68 feet.

In the WW-SF system, Doug Rowell provided equipment and field management. A complete list of field operations and inputs appears in Table 1. After harvest (start of fallow), wheat stubble was left standing and undisturbed through the winter. Glyphosate herbicide (Roundup) was applied at 11 fluid oz/acre in February in two of six years to control winter-annual grass weeds, mostly downy brome (*Bromus tectorum* L.). Primary tillage in March to a soil depth of 6 inches was conducted with either a tandem offset disk with 22-inch-diameter circular blades or an undercutter equipped with overlapping 18-inch-wide high-pitch V-shaped sweeps spaced 12 inches apart. An average of two secondary tillage operations were conducted during late spring and midsummer using a rodweeder (a 1-inch-square rotating rod) at a depth of 4 inches to control Russian thistle and other broadleaf weeds. Ammonium thiosulfate was injected into fallow with shanks spaced 18 inches apart in late spring in two of six years when it was felt application was economically justified based on stored soil water, i.e., yield potential. Soft white WW 'Eltan' or 'Malcolm' was planted at a rate of 27 lb/acre with a modified Flexi-coil™ (Flexi-coil, Saskatoon, Canada) deep-furrow drill with 21-inch-wide row spacing into moist soil in late August of 1996 and 1997. When seed-zone water was insufficient (less than 11% by volume, August 1998, 1999, 2000, 2001), planting was delayed until mid-November after fall rains had wet the soil surface and a John Deere™ (John Deere Co., Moline, IL) 9300 series hoe-opener drill with 10-inch-wide row spacing was used to plant WW at 63 lb/acre. Adequate WW stands that averaged nine plants per square foot were achieved each year and no winter kill of plants occurred using either of the two planting methods. In-crop broadleaf weeds were controlled in March with 2,4-D ester herbicide at 16 fluid oz/acre or with 2,4-D amine herbicide at 21 fluid oz/acre in April when WW

**Table 1. Field operations and inputs for winter wheat - summer fallow (WW-SF) compared with continuous annual no-till hard red spring wheat (HRSW) during six crop years (1997-2002).**

Month	Winter wheat - summer fallow system		
	Winter wheat	Summer fallow	Annual hard red spring wheat
Aug	WW planted 8 inches deep at 27 lb/ac <sup>-1</sup> in 21-inch-wide rows in 1996 and 1997. <sup>†</sup> Stands failed in 1997. <sup>‡</sup>		Postharvest herbicide: 32 fluid oz/acre <sup>-1</sup> Surefire (paraquat + diuron) in 1997, 1998, and 2000.
Nov	WW planted 1 inch deep at 63 lb/ac <sup>-1</sup> in 10-inch-wide rows after the onset of fall rains in 1997, 1998, 1999, 2000, and 2001.		
Feb		Herbicide: 11 fluid oz/acre <sup>-1</sup> glyphosate in 1997 and 2000 only.	Herbicide: 11 fluid oz/acre <sup>-1</sup> glyphosate in 5 of 6 years.
Mar	In-crop broadleaf herbicide: 16 fluid oz/acre <sup>-1</sup> 2,4-D ester in 1997, 1998 and 1999; 21 fluid oz/acre <sup>-1</sup> 2,4-D amine in 2000, 2001, and 2002.	Primary tillage: tandem offset disk with 22-inch-diam. blades to a depth of 6 inches in 1997, 1999, and 2002; undercutter with 18-inch-wide V-shaped sweeps spaced 12 inches apart in 1998, 2000, 2001.	HRSW planted 1 inch deep at 68 lb/acre <sup>-1</sup> and fertilized at 17 lb N, 6 lb P, and 5 lb S acre <sup>-1</sup> in 10-inch-wide rows (1997, 1998, 1999) and 8-inch-wide rows (2000, 2001, 2002) in one pass with Cross-slot no-till drill.
Apr		Fertilizer injection: Aqua NH <sub>3</sub> at 25 lb/acre <sup>-1</sup> plus S at 8 lb/acre <sup>-1</sup> in 1996 and 1997 only.	In-crop broadleaf herbicide: 21 fluid oz/acre <sup>-1</sup> 2,4-D amine in 1997, 2000, 2001, and 2002; 4 fluid oz/acre <sup>-1</sup> Banvel (dicamba) in 1998 and 2000.
May		First rodweeding, 4-inch depth	
June			
July	Grain harvest	Second rodweeding, 4-inch depth	Grain harvest

<sup>†</sup> Although placed 8 inches below the preplant soil surface, only 6 inches of soil covered the seed as some soil was stacked in furrow ridges by the deep-furrow drill.

<sup>‡</sup> Stands of early planted winter wheat failed in 1997 due to soil crusting caused by rain showers prior to seedling emergence. Early planting of winter wheat was not attempted in 1998, 1999, 2000, and 2001 due to dry soil conditions.

was in the tillering phase of development (Table 1).

In the continuous annual no-till HRSW system, an average 12 fluid oz/acre glyphosate herbicide was applied in January or February to control winter annual grass weeds in five of six years. In late February or early March, HRSW 'Kulm' or 'Scarlet' was planted at 68 lb/acre using two separate custom-built drills equipped with Cross-slot™ (Baker Manufacturing, Christchurch, New Zealand) notched-coulter openers on 10-inch-wide (1997, 1998, 1999) and 8-inch-wide (2000, 2001, 2002) row spacing for simultaneous and precision placement of seed and fertilizer in the same row. Fertilizer was placed 0.75 inch below and 1.25 inch to the side of the seed. Solution 32 provided the liquid base to supply a 6-year average of 42 lb N, 15 lb P, and 11 lb S per acre per year. Nitrogen fertilizer rate was based on 3.5 lb of available N for each expected bushel of grain yield to achieve 14% grain protein content of HRSW as described by Mahler and Guy (1998). The wheat cultivars used in the study were considered the best available based on multiple site and year yield data from the Washington State University cereal variety testing program. Excellent HRSW stands that averaged 12 plants per square foot were consistently achieved. In-crop broadleaf weeds were controlled with either 4 fluid oz/acre Banvel herbicide when wheat was at the two- to five-leaf stage of growth or 2-4,D amine at 21 fluid oz/acre when wheat was in the tillering phase of growth. Postharvest herbicide of 22 fluid oz./acre Surefire (paraquat + diuron) was applied in July in three of six years to control Russian thistle growth, seed production, and water use. Thus, two or three herbicide applications (preplant, in-crop, and postharvest) were required each year to control grass and broadleaf weeds in the continuous annual no-till HRSW system (Table 1). Two or three annual herbicide applications such as those used in the study are common for spring wheat production in the inland Pacific Northwest.

### Measurements

Soil water was measured to a depth of 6 feet in all plots immediately after grain harvest each year in early July (beginning in 1997) and again in late February or early March prior to primary tillage (for fallow) or planting (for annual

HRSW). Soil volumetric water content in the 12- to 72-inch depth was measured in 6-inch increments by neutron thermalization (Hignett and Evett, 2002). Volumetric soil water content in the 0- to 12-inch depth was determined from two 6-inch core samples using gravimetric procedures (Top and Ferre, 2002). In addition, volumetric seed-zone soil water content in SF plots was measured in 1-inch increments to a depth of 9 inches using an incremental soil sampler in late August of 1999, 2000, and 2001.

Grain yield was determined by harvesting the grain from plants in a swath through each 300-foot-long plot using either i) a commercial combine having a 30-foot-wide cutting platform and auguring grain into a truck mounted on weigh pads (1997-2000), or ii) a plot combine featuring a 5-foot-wide cutting platform, collecting grain in a cloth sack, and weighing grain on a digital scale accurate to 1 gram (2001-2002). Head density and total aboveground dry biomass production were measured by hand-cutting plants from 3-foot-long row segments in three locations in each plot just prior to harvest in July. Unit area for the clipped row of each treatment was then calculated based on drill row spacing. Whole-plant samples were placed in a low-humidity greenhouse for 7 days, then weighed. Kernels per head was calculated based on heads per foot and thousand kernel weight after passing heads through a hand-fed thresher. Straw production was determined by subtracting the weight of the grain from the whole-plant weight.

Russian thistle population and dry biomass were determined in HRSW plots (Russian thistle was not present in WW plots) immediately prior to grain harvest in 1997 and 1998 by first counting, then clipping and gathering the aboveground portion of all Russian thistle plants within a 1-meter-diameter hoop randomly positioned in each plot of all replications. Russian thistle plants were placed in paper bags and allowed to air dry in a low-humidity greenhouse before weighing on a digital scale accurate to 1 gram.

### Economic Assessment

Standard enterprise budgets were constructed to assess the profitability of the two cropping systems. Costs are based on the actual sequence of operations conducted on the research plots, and

assume the farmer-cooperator's farm-scale machinery (Table 1). Fertilizer, herbicide, seed, and other input rates are averages used during the experiment. Total costs include a market return for the farmer's land, machinery, and labor. Under such total cost budgeting, a "fair or normal profit" would be zero. This means that crop receipts exactly cover a market wage for the farmer's labor, a market rent for land and machinery, and all other production expenses. Grain yields are those measured from the experiment. All cost and revenue figures are presented on a rotational acre basis; for example, for WW-SF, one-half acre of WW and one-half acre of fallow. This ensures comparability on a standard \$ acre<sup>-1</sup> basis for differing crop rotations.

Six-year average crop prices of \$3.43 per bushel for WW and \$4.41 per bushel for HRSW were used. For HRSW, the analysis used the 6-year average price premium of \$0.05 per bushel for every 0.25% from 14% to 15.5% protein, and a penalty of \$0.11 per bushel for each 0.25% protein shortfall below 14%. Protein premiums and penalties varied each year as did price margins in the comparison of HRSW and soft white wheat.

Government payments are not included in the net revenue results as the emphasis is on market profitability rather than on varying government payments. Including decoupled direct government payments from this time period would not influence the ranking of the two treatments as these payments were not tied to choice of cropping system.

### Statistical Procedures

Analysis of variance was conducted for PSE, grain yield, grain yield components, straw production, and economic net returns. The procedure used to compare treatment means was Fisher's protected least significant difference. All statistical tests were done at the 5% level of significance. Significant year x treatment interactions were observed for grain yield components. Because of these interactions, the data were analyzed separately by year.

## RESULTS AND DISCUSSION

### Precipitation and Soil Water

Annual crop-year (1 Aug – 31 July) precipitation ranged from 4.4 to 9.5 inches and

averaged 6.0 inches over 6 years (Table 2). Precipitation was much greater than the long-term average in 1997 and 1998, but drought occurred during the final four years of the experiment. Over-winter precipitation (that occurring from grain harvest until planting of HRSW and primary tillage of SF plots in late February-early March) was 69% of the crop-year total averaged over 6 years.

Over-winter PSE averaged 71% for no-till HRSW stubble compared with 65% for WW stubble (Table 2), but no significant PSE differences occurred in any year or when analyzed over years. The trend toward greater PSE in no-till HRSW plots was probably because these soils were drier than in WW plots, due to extensive soil water use by an average five Russian thistle plants per square foot. Russian thistle plants produced an average 1130 lb/acre dry biomass (data not shown) present in HRSW during the two wet years (1997 and 1998), despite the timely application of in-crop broadleaf herbicide. Russian thistle is a C<sub>4</sub> plant characterized by high water use and prolific seed production (Schillinger and Young, 2000), which has long plagued spring-planted crops in dry regions of the western United States (Dewey, 1893). Russian thistle is not as big a problem in WW, since WW has more vigorous early spring growth and canopy closure to compete against Russian thistle than does spring wheat. The HRSW plots had 1.1 inches less soil water than WW plots by harvest in July 1998, and soil water in the 6-foot profile remained significantly less in HRSW stubble than in WW stubble throughout the four subsequent drought years (data not shown).

Summer fallow 12-month PSE ranged from 6% to 30% and averaged 21% (Table 2). The worst SF year (and crop year) was 2001 when only 2.6 inches of over-winter precipitation occurred, and the wetting front in early March extended only to a soil depth of 12 inches (data not shown), resulting in a net gain of only 0.28 inches of water (6% PSE) during the SF period (Table 2).

Early planting of WW into moist soil was conducted in August of 1996 and 1997. Stands failed in 1997 due to soil crusting caused by rain that occurred before germinating WW seedlings could emerge through 6 inches of soil cover. Early planting of WW was not attempted during the

**Table 2. Precipitation (6-year) and precipitation storage efficiency (5-year) with continuous annual no-till hard red spring wheat (HRSW) vs. winter wheat - summer fallow (WW-SF). Precipitation storage efficiency (PSE) is the percentage of precipitation that was stored in the soil.**

Crop year	Annual (crop-year) precipitation <sup>†</sup>	Over-winter precipitation	Over-winter PSE <sup>‡</sup>		12-mo PSE Tilled SF
			HRSW stubble	WW stubble	
inches			%		
1997	9.45	7.40	§		
1998	7.87	4.49	72	70	30
1999	4.41	2.99	65	62	18
2000	4.75	3.19	83	75	29
2001	4.37	2.60	57	57	6
2002	5.35	4.02	78	62	22
Avg.	6.02	4.12	71¶	65	21

† Crop-year precipitation is from 1 August to 31 July.

‡ Over-winter precipitation occurs from grain harvest in the summer to planting (no-till HRSW) or primary tillage (SF) in late winter.

Soil water measurements for all plots were always obtained within a 2-day interval.

§ The first soil water measurements were obtained in February 1997, thus PSE values are not available for 1997.

¶ There were no significant differences in over-winter PSE between HRSW stubble and WW stubble in any year or when analyzed over all years.

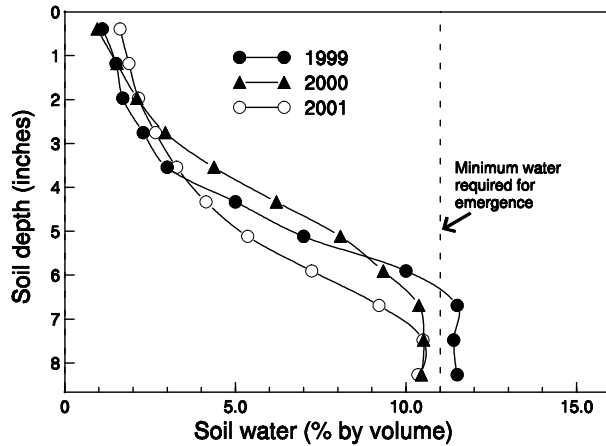


Figure 1. Seed-zone soil water content in summer fallow in late August during 3 drought years.

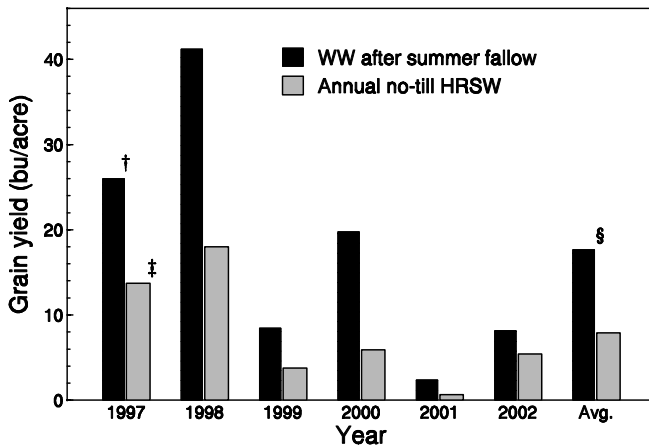


Figure 2. Grain yield of winter wheat (WW) after summer fallow (one crop every two years) compared with continuous annual no-till hard red spring wheat (HRSW) during 6 years in the Horse Heaven Hills, Washington.

† Winter wheat yield in 1997 is the average from several neighboring fields, not from replicated plots, thus statistical analysis is not possible in 1997.

‡ HRSW grain yield is from replicated plots during all 6 years.

§ Statistical comparison of average grain yield is for 5 years (1998 to 2002). Grain yield of WW after SF was significantly ( $P < 0.05$ ) greater than grain yield of annual HRSW each year and when averaged over the 5 years.

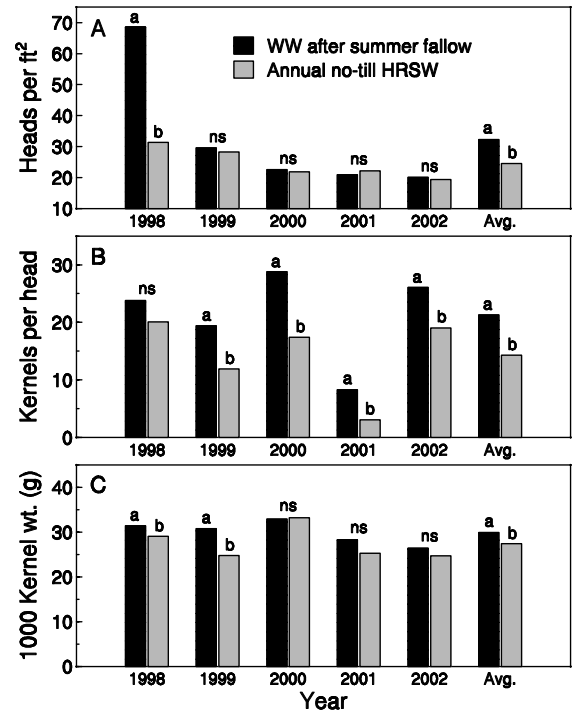


Figure 3. Grain yield components [heads per ft<sup>2</sup> (A), kernels per head (B), and thousand kernel weight (C)] of winter wheat (WW) after summer fallow compared with continuous annual no-till hard red spring wheat (HRSW) during 5 years. Within-year means followed by a different letter are significantly different at  $P < 0.05$ . The term “ns” indicates no significant difference.

ensuing drought years (1998 to 2002), as seed-zone water content in SF was insufficient for seedling emergence (Fig. 1). Instead, WW was planted shallow (1 inch deep) in late October or early to mid-November after the onset of fall rains.

### **Grain Yield, Yield Components, and Straw Production**

Grain yield averaged over years was 7.9 bu/acre for annual HRSW and 17.7 bu/acre for WW after SF (Fig. 2). Record-setting high WW grain yield for the Rowell farm of 41 bu/acre, and also the 6-year high grain yield for annual HRSW of 18 bu/acre (Fig. 2), were achieved in 1998 largely due to 1.5 inches of rain during a 2-day period in late May. During the ensuing drought years (1999-2002), WW produced economically viable yield in 2000, but otherwise WW and HRSW yields ranged from less than 1.0 to 8.5 bu/acre (Fig. 2); these yields are viewed by farmers as crop failures.

Heads per square foot unit area for WW and HRSW were significantly different in 1998, but not in the drought years that followed (Fig. 3a). Conversely, WW produced more kernels per head than HRSW from 1999-2002, but in 1998 there were no differences (Fig. 3b). Small but significant differences in kernel weight were found between WW and HRSW in 1998 and 1999 but not in the other years (Fig 3c). These data agree with Arnon (1972) and Garcia del Moral et al. (2003), who reported that spikes per unit area is the most important yield component for rainfed wheat in nondrought years, but under conditions of extreme water stress the number of kernels per head has the greatest effect on yield.

Straw production for annual HRSW ranged from 700 (2001) to 1900 (1998) lb/acre and averaged 1200 lb/acre during the 6 years. For WW after SF, straw production ranged from 1000 (2002) to 5700 (1998) lb/acre and averaged 2400 lb/acre. Thus, total straw production between the two systems over the 6 years was about the same.

### **Economics**

Table 3 shows market gross returns, total costs, and net returns for the WW-SF and annual HRSW systems for 1997-2002. Over 6 years, HRSW averaged a loss of -\$44 per acre per year, while WW-SF lost only -\$6 per acre per year. The

returns reflect appropriate protein premiums or discounts for HRSW each year. Annual net returns ranged from -\$60 to -\$25 per acre per year for HRSW and from -\$23 to +\$16 per acre per year for WW-SF. Farm-specific government payments might add another \$10 per acre per year return for both cropping systems. These payments put WW-SF in the black on average, but not annual HRSW.

Production costs for annual HRSW averaged \$73 per acre per year and were double those for WW-SF at \$36 per acre per year (Table 3). Although the annual HRSW production costs are low compared with higher precipitation regions of the Pacific Northwest, the regular use of fertilizer, two or three herbicide applications annually (see Table 1), plus planting and harvesting every acre every year elevates these costs relative to WW-SF. Costs for the WW-SF system, computed using Doug Rowell's practices, are among the lowest wheat production costs observed in the United States (Young et al., 2001). During dry years, no fertilizer was applied. In-crop broadleaf weed control was limited to inexpensive 2,4-D herbicide. Farm-grown grain was kept and treated for seed.

Many farmers and businessmen define economic risk as "probability of loss." Annual no-till HRSW failed to cover total costs, exclusive of government payments, in all 6 years, whereas WW-SF covered total costs, without government payments, in three of the six years (Table 3).

### **SUMMARY AND FURTHER RESEARCH DIRECTIONS**

Lack of residue cover and surface roughness on summer-fallowed soils in the Horse Heaven Hills frequently leads to wind erosion as well as poor air quality in downwind urban areas. No-till farming is widely recognized throughout the world for excellent control of wind and water erosion, energy savings, and improved soil quality (Doran et al., 1996). Despite these benefits, continuous annual no-till HRSW was not economically competitive with the WW-SF system during either the relatively wet years or the drought years in this study. Annual HRSW lagged WW-SF in profitability by an average of \$38 per acre per year. On a 7000-acre dryland farm, production of continuous annual HRSW would result in a net loss of \$266,000 per year, compared

**Table 3. Annual costs and market returns for winter wheat – summer fallow (WW-SF) compared with continuous annual no-till hard red spring wheat (HRSW) from 1997 to 2002.**

Year	Rotation	Gross returns	Total costs	Net returns <sup>†</sup>
			\$ acre <sup>-1</sup>	
1997	WW-SF	45.58	39.51	6.07
	HRSW	40.00	83.61	-43.61
1998	WW-SF	70.86	54.82	16.04
	HRSW	63.90	88.53	-24.63
1999	WW-SF	14.62	29.81	-15.19
	HRSW	16.18	69.94	-53.79
2000	WW-SF	34.06	33.90	0.16
	HRSW	24.66	62.88	-38.22
2001	WW-SF	4.09	26.79	-22.70
	HRSW	2.80	62.59	-59.79
2002	WW-SF	14.79	32.97	-18.18
	HRSW	23.87	69.18	-45.31
6-yr avg.	WW-SF	30.67	36.30	-5.63 a
	HRSW	28.57	72.79	-44.22 b

<sup>†</sup> The 6-year average net returns for WW-SF and continuous annual HRSW followed by a different letter are significantly different at  $P < 0.05$  (LSD \$7.59 acre<sup>-1</sup>) and  $P < 0.001$  (LSD \$20.25 acre<sup>-1</sup>).

with the standard WW-SF (3500 acres in WW, 3500 acres in SF) system; clearly not a viable alternative given current technology.

Future research efforts in the HHH as a result of this paper should focus on

- i) Chemical SF as a replacement for tilled SF. Some newly developed soil-residual broadleaf herbicides have shown excellent and extended control of Russian thistle in chemical SF. Late-August planting of WW into chemical SF is not feasible due to accelerated drying of the seed zone—as compared with seed-zone moisture in tilled SF (Hammel et al., 1981). However, farmers in the HHH only have adequate seed-zone moisture for planting WW in August about 50% of the time with tilled SF. Chemical SF would be acceptable to many farmers in the HHH if government farm programs helped offset the cost of herbicides and the possible reduction in yield due to delayed planting that can occur with chemical SF compared with tilled SF.
- ii) Development of spring wheat cultivars that have fast and early prostrate growth habit to compete against Russian thistle. Different market classes of spring wheat may provide more favorable economics than HRSW. For example, continuous annual no-till soft white spring wheat (no protein requirement and with higher yield potential than HRSW) has been economically competitive with WW-SF in a long-term cropping systems experiment in a 11.4-inch precipitation area in eastern Washington (Juergens et al., 2004).
- iii) Flexible cropping options that depend on the quantity of over-winter soil water storage.

Finally, although we commend farmers in the HHH for their existing conservation efforts and concerns, further soil-saving refinements in the tilled WW-SF can be made. Undercutter sweep implements with thin, 28-inch-wide, adjustable-pitch and overlapping V-blades with excellent depth control have retained maximum amounts of surface residue and roughness during SF with no adverse agronomic or economic effects (Schillinger, 2001; Janosky et al., 2002). Further details on controlling wind erosion and air quality on Columbia Plateau croplands in the Pacific Northwest are described by Papendick (2004).

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**Footnote:** Mention of product and equipment names does not imply endorsement by the authors or by Washington State University.

## REFERENCES

- Arnon, I. 1972. Crop production in dry regions. Volume I: Background and principles. Leonard Hill, London.
- Dewey, L.H. 1893. The Russian thistle and other troublesome weeds in the wheat region of Minnesota and North and South Dakota. USDA Farmers' Bull. 10. U.S. Dept. of Agriculture, Washington, D.C.
- Donaldson, E. W.F. Schillinger, and S.M. Dofing. 2001. Straw production and grain yield relationships in winter wheat. *Crop Sci.* 41:100-106.
- Doran, J. W., M. Sarrantonio and M. A. Liebig. 1996. Soil health and sustainability. *In:* D.L. Sparks, (ed.) *Advances in Agronomy.* Academic Press, Inc., Newark, DE, pp. 1-54.
- Garcia del Moral, L.F., Y. Rharrabti, D. Villegas, and C. Royo. 2003. Evaluation of grain yield and its components in durum wheat under Mediterranean conditions: An ontogenic approach. *Agron. J.* 95:266-274.
- Hammel, J.E., R.I. Papendick, and G.S. Campbell. 1981. Fallow tillage effects on evaporation and seedzone water content in a dry summer climate. *Soil Sci. Soc. Am. J.* 45:1016-1022.
- Hignett, C., and S.R. Evett. 2002. Methods for measurement of soil water content: Neutron thermalization. p. 501-521. *In* J.H. Dane and G.C. Top (eds.) *Methods of soil analysis. Part 4 – Physical methods.* SSSA Book Series: 5, Soil

- Science Society of America, Madison, WI.
- Janosky, J.S., D.L. Young, and W.F. Schillinger. 2002. Economics of conservation tillage in a wheat-fallow rotation. *Agron. J.* 94:527-531.
- Juergens, L.A., D.L. Young, W.F. Schillinger, and H.R. Hinman. 2004. Economics of alternative no-till spring crop rotations in Washington's wheat-fallow region. *Agron. J.* 96:154-158.
- Lee, B.H. 1998. Regional air quality modeling of PM-10 due to windblown dust on the Columbia Plateau. M.S. thesis. Dept. of Civil and Environmental Eng., Washington State University, Pullman, WA.
- Leggett, G.E., R.E. Ramig, L.C. Johnson, and T.W. Masee. 1974. Summer fallow in the Northwest. p. 110-135. *In* Summer Fallow in the Western United States. Conservation Research Report No. 17, Agricultural Research Service, U.S. Dept. of Agriculture, Washington, D.C.
- Mahler, R.L. and S.O. Guy. 1998. Northern Idaho fertilizer guide: Spring wheat. University of Idaho Current Info. Series No. 921, Moscow, ID. 8 p.
- Papendick, R.I. 2004. Farming with the wind II: Wind erosion and air quality control on the Columbia Plateau and Columbia Basin. College of Agriculture, Human, and Natural Resource Sciences Special Report EB 1972 by the Columbia Plateau PM-10 Project. University Publishing, Washington State University, Pullman, WA.
- Papendick, R.I., M.J. Lindstrom, and V.L. Cochran. 1973. Soil mulch effects on seedbed temperature and water during fallow in eastern Washington. *Soil Sci. Soc. Am. Proc.* 37:307-314.
- Rasmussen, J.L. 1971. Soil survey of Benton County area, Washington. Soil Conservation Service, U.S. Dept. of Agriculture, Washington, DC.
- Schillinger, W.F. 2001. Minimum and delayed conservation tillage for wheat-fallow farming. *Soil Sci. Soc. Am. J.* 65:1203-1209.
- Schillinger, W.F. and F.L. Young. 2000. Soil water use and growth of Russian thistle after wheat harvest. *Agron. J.* 92:167-172.
- Top, G.C. and P.A. Ferre. 2002. Methods for measurement of soil water content: Thermogravimetric using convective oven-drying. p. 422-424. *In* J.H. Dane and G.C. Top (eds.) *Methods of soil analysis. Part 4 – Physical methods.* SSSA Book Series: 5, Soil Science Society of America, Madison, WI.
- Young, D.L., H.R. Hinman, and W.F. Schillinger. 2001. Economics of winter wheat-summer fallow vs. no-till spring wheat in the Horse Heaven Hills, Washington. Washington State University Cooperative Extension Bulletin 1907, Pullman, WA. Online at: <http://farm.mngt.wsu.edu/nonirr.htm> (verified 8 Jan. 2004).
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