Economics of Conservation Tillage in a Wheat–Fallow Rotation

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ABSTRACT

Wind erosion and blowing dust on conventionally tilled winter wheat (*Triticum aestivum* L.)–summer fallow cropland in eastern Washington, USA, reduces soil productivity and can contribute to poor air quality. Conservation tillage during fallow has long been known to curtail erosion and dust, but conventional tillage (CT) is still practiced on more than 80% of the cropland in the region. This paper reports the economic results of a 5-yr (1995–1999 harvest years) tillage system study at Lind, WA. The site averages 244 mm of annual precipitation, and the soil is a Shano silt loam (coarse-silty, mixed, superactive, mesic Xeric Haplocambids). Tillage systems were (i) CT, (ii) minimum tillage (MT; herbicides and tillage), and (iii) delayed MT (DMT; herbicides and delayed tillage). Wheat grain yield across years ranged from 1.79 to 5.20 Mg ha^{-1}, but there were no differences in grain yield among tillage systems in any year or when analyzed across years. Tillage systems were economically equivalent based on market returns over total production costs, but DMT was slightly less profitable than CT based on market returns over variable costs. Economic analysis indicates that no subsidies should be required to entice producers to switch from CT to MT fallow because the systems are equally profitable. Because there is no short- or long-term economic sacrifice for converting to the soil-saving MT system, it represents a *win-win* solution for farmers and the environment.

WHILE THE LAND AREA under summer fallow in the USA has declined during the past three decades, the winter wheat–fallow rotation remains the dominant cropping system in areas receiving <350 mm of annual precipitation (Dhuyvetter et al., 1996; Smith and Young, 2000). In eastern Washington state and north-central Oregon, winter wheat–summer fallow is the prevailing cropping system on approximately 2.0 million ha. Farmers in the northern Great Plains have markedly reduced wind erosion on fallow cropland by adopting minimum tillage (MT) and no-tillage practices, and recent evidence shows similar reductions in windborne dust and wind erosion in the Pacific Northwest (Lee, 1998).

The Conservation Tillage Information Center (CTIC, 1998) reported that farmers in the western Great Plains and Pacific states used MT and no-tillage on 34% of cropland. However, in Washington state, only 26% of cropland was in MT and no-tillage (CTIC, 1998). In east-central Washington, where annual precipitation typically ranges from 150 to 300 mm, even MT fallow is rare. For example, in Adams County, the heart of Washington's wheat–fallow area, conventional tillage (CT) is still practiced on 88% of the cropland.

Most previous studies of the economics of no-tillage and MT in wheat–fallow systems have been conducted in the U.S. Great Plains and the Canadian Prairies. Reviews of this work have found that the relative profitability of these reduced-tillage systems in semiarid regions varied by location; however, reduced tillage generally increased net returns when crop planting intensity also increased (Dhuyvetter et al., 1996). While these systems offer recognized soil and air quality benefits, some researchers have reported higher production costs for no-till (Norwood and Currie, 1998; Zentner et al., 1996). Smith et al. (1996) reported that the presence of difficult-to-control weeds can greatly elevate herbicide and total production costs for no-till in semiarid regions. However, recent case studies of experienced no-till farmers in a semiarid region of eastern Washington revealed that their production costs for spring-sown crops were lower than with CT (Camara et al., 1999).

Conventional tillage practices during fallow are intensive and often leave the soil vulnerable to erosion. A soil surface deficient in residue, clods, and roughness can pose a serious wind erosion threat (Fryrear and Bilbro, 1994). Conservation tillage systems in the inland Pacific Northwest generally employ noninversion implements such as wide-blade V-sweeps for primary spring tillage, combined with use of herbicides in lieu of one or two tillage operations, and retain higher levels of surface residue and soil roughness during fallow compared with CT (Papendick, 1998). Lee (1998) predicted that suspended dust particulates that were 10 μm (PM-10) and smaller in Spokane, WA, would be reduced by 31 to 54% if conservation tillage or no-tillage replaced conventional summer fallow.

Both the Spokane and Tri-Cities urban areas in eastern Washington have failed on several occasions to meet the Federal Air Quality Standards for PM-10. One such occasion was during a massive dust storm on 25 Sept. 1999 when PM-10 reached 405 μg^{-3}, nearly three times the national allowable standard of 150. On that day, seven motorists were killed and 22 injured in a multivehicle collision in near-zero visibility on Interstate 84 near Pendleton, OR. Violations of federal air quality standards mandate that regional air quality agencies develop plans to solve this problem.

Why don't most wheat–fallow farmers in the inland Pacific Northwest practice conservation tillage? Some farmers cite concerns of inadequate seed-zone water for winter wheat stand establishment (Lindstrom et al., 1974), difficulty in controlling downy brome (*Bromus tectorum*) and other grass weeds (Ogg, 1993), and plugging of grain drills due to excessive residue. Concerns

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Abbreviations: CT, conventional tillage; DMT, delayed minimum tillage; MT, minimum tillage.

about the financial risk from investing in conservation tillage implements also appear to underlie the reluctance by some eastern Washington farmers to adopt conservation tillage fallow systems (Juergens et al., 2001). This paper reports on grain yield performance and profitability of MT and delayed MT (DMT) compared with CT for wheat–fallow farming in semiarid eastern Washington.

MATERIALS AND METHODS

Description of Experiment

A wheat–fallow rotation tillage system experiment was conducted from August 1993 to July 1999 at the Washington State University Dryland Research Station at Lind, Washington. Although the first fallow operations occurred in 1993, the research is referred to as a 5-yr study as wheat harvests occurred from 1995 through 1999 (Table 1). The Shano silt loam soil is more than 2 m deep with $<2\%$ slope. The experimental design was a randomized complete block of three tillage systems replicated four times. Individual plots were 18 by 46 m, which allowed the use of commercial-size farm equipment. Paired adjacent parcels of land were used so that data could be collected from both crop and fallow phases of the study each year. The three tillage management systems were (i) CT—standard frequency and timing of tillage operations using implements commonly used by farmers; (ii) MT—standard frequency and timing of tillage operations, but herbicides were substituted for tillage when feasible and a noninversion V-sweep implement with attached rolling harrow was used for primary spring tillage; and (iii) DMT—similar to MT, except primary spring tillage with a noninversion V-sweep was delayed until at least mid-May. The DMT system was included to test its impact on soil moisture retention and wind erosion control as well as economic feasibility. A complete list of field operations and timing for each tillage system throughout the study is shown in Table 1. Detailed descriptions of tillage and other field operations for all tillage systems are reported in Schillinger (2001).

Economic Analysis

Standard enterprise budgeting techniques were used to estimate average fixed and variable costs of production for each tillage system (Janosky, 1999; Hinman and Esser, 1999). Fixed costs include depreciation, interest, taxes, housing, and insurance on machinery and a farm overhead charge. Land costs were based on the region's prevailing two-thirds tenant–one-third landlord crop share rent, which varied by annual yields. Variable costs include seed, fertilizer, herbicides, crop fire and hail insurance, fuel, repairs, and labor. Production costs for each tillage system were based on the actual sequence of operations conducted in the experiment (Table 1) but assume typical farm-scale machinery for the region. The wide-blade V-sweep was the only additional implement required for switching from CT to MT or DMT. Fertilizer, herbicide, and seed rates are those used in the Lind experiment (Table 1). Grain yields are the 1995 to 1999 averages recorded from the experiment (Table 2). All cost and revenue figures are presented per rotational hectare. For example, for winter wheat–summer fallow, costs and revenues are computed for 0.5 ha of winter wheat and 0.5 ha of fallow. This correctly portrays the average return per hectare per year of a farmer who has one-half of the farm in fallow and one-half in winter wheat. For the economic analysis, it is assumed that farmers in this region will incur the cost of replanting their winter wheat crop to spring wheat 1 out of 5 yr due to inadequate winter wheat stands or winter kill. This occurred in the Lind experiment for all tillage systems due to inadequate seed-zone water for planting winter wheat in September 1994.

The wheat prices used, \$144.02 Mg^{-1} for soft white wheat and \$187.3 Mg^{-1} for hard red spring wheat, are regional benchmark, 1993 through 1997 marketing-year averages of farm-gate prices in the study area. A sensitivity analysis is included to show the effects of a broader range of wheat yields and prices, including prices below \$110 Mg^{-1}, as observed in 1998 and 1999. Net market returns are defined as market returns over production costs. Government transition, supplemental, and loan deficiency payments, which were substantial in 1998 and 1999, are not included. Adding government payments

Table 1. Field operations for the three tillage management systems during the six fallow cycles (1993–1999) at Lind, WA.

Date	Conventional tillage (CT)	Minimum tillage (MT)	Delayed minimum tillage (DMT)
Aug.	Sweep—30-cm shank spacing, 36-cm-wide sweeps, 13-cm depth. Sweeping was not conducted in 1996, 1997, and 1998.	Herbicide—0.38 kg a.e. ha^{-1} glyphosate + 0.67 kg a.e. ha^{-1} 2,4-D in1993; 0.85 kg a.e. ha^{-1} glyphosate in 1994 and 1995. Not required in 1996, 1997, and 1998.	Herbicide—0.38 kg a.i. ha^{-1} glyphosate + 0.67 kg a.e. ha^{-1} 2,4-D in 1993; 0.85 kg a.e. ha^{-1} glyphosate in 1994 and 1995. Not required in 1996, 1997, and 1998.
Nov.	Chisel—60-cm shank spacing, straight point, 25-cm depth.	Chisel—120-cm shank spacing, straight point, 25- to 40-cm depth. Not conducted in 1996. Rotary subsoiler, 40-cm depth in 1997 and 1998.	Chisel—120-cm shank spacing, straight point, 25- to 40-cm depth. Not conducted in 1996, 1997, and 1998.
Feb.	Herbicide—0.32 kg a.e. ha^{-1} glyphosate.	Herbicide—0.32 kg a.e. ha^{-1} glyphosate.	Herbicide—0.32 kg a.e. ha^{-1} glyphosate.
Mar.†‡	Primary tillage—cultivator, overlapping 18-cm-wide sweeps, 13-cm depth + 5-bar spring-tooth harrow (two passes). Tandem disk, 13-cm depth (one pass) in 1997 and 1998.	Primary tillage—undercutter, overlapping 80-cm-wide V-blades, 13-cm depth + rolling harrow.	
Apr.	Anhydrous NH_3–N injection at 45 kg ha^{-1}		
May	First rod weeding, 10-cm depth	First rod weeding, 10-cm depth	Primary tillage—undercutter, overlapping 80-cm-wide V-blades, 13-cm depth + rolling harrow
June	Second rod weeding, 10-cm depth	Second rod weeding, 10-cm depth	First rod weeding, 10-cm depth
July	Third rod weeding, 10-cm depth	Third rod weeding, 10-cm depth	Second rod weeding, 10-cm depth
Sept.§	Sown to winter wheat at 45 kg ha^{-1}.	Sown to winter wheat at 45 kg ha^{-1} + aqua NH_3–N injection at 45 kg ha^{-1}.	Sown to winter wheat at 45 kg ha^{-1} + aqua NH_3 injection at 45 kg ha^{-1}.

† All tillage systems were sown to hard red spring wheat in March 1995 because winter wheat failed due to dry seed-zone conditions in September 1994.

‡ Skew tread to cut and incorporate high quantities of residue in all tillage systems on 1 March and again on 15 May in 1998.

§ MT and DMT systems were first *blind-sown* in 1997 with just the drill's packer wheels to pass through 2000 kg ha^{-1} residue without plugging during actual sowing.

Table 2. Annual wheat grain yield by three fallow tillage systems.

Fallow tillage system	1995†	1996	1997	1998	1999	Avg.‡
	Mg ha^{-1}					
Conventional (CT)	1.79	3.52	5.13	3.89	2.32	3.72
Minimum (MT)	1.91	3.76	5.20	3.89	2.69	3.89
Delayed minimum (DMT)	1.79	3.73	4.94	3.58	2.48	3.68
	NS	NS	NS	NS	NS	NS

† Fallow tillage systems were initiated in August 1993, and the first winter wheat was sown in September 1994. Due to insufficient seed-zone water, the winter wheat stand failed in fall 1994, and hard red spring wheat was sown in March 1995. Within-column means show no significant grain yield differences at $P < 0.05$ in any year or when averaged across years.

‡ Average soft white winter wheat yield (1996–1999).

would not influence the ranking of the tillage systems as the decoupled transition and supplemental payments do not vary with the tillage system. However, at the whole-farm level, these payments would affect judgements about economic viability, regardless of tillage choice.

RESULTS AND DISCUSSION

Yields, Residue, and Water Storage

Winter wheat grain yield from 1995 to 1999 ranged from 1.79 to 5.20 Mg ha^{-1}. There were no significant statistical differences in grain yield among tillage systems within any year or in the 5-yr average (Table 2). While not statistically significant, the yields for MT exceeded or equaled those for CT every year. Retention of surface residue at the end of the 13-mo fallow period averaged 770, 1390, and 1440 kg ha^{-1} for CT, MT, and DMT, respectively (Schillinger, 2001). Using CT, the minimum quantity of surface residue required for highly erodible soils for government farm program compliance (390 kg ha^{-1}) was not achieved in one year of the experiment and was only marginally met in another, whereas ample residue was present in all years in the MT and DMT systems. In addition, twice the amount of surface clod mass and a rougher surface was achieved with MT and DMT compared with CT. Averaged over all fallow cycles, soil water content in the 0- to 15-cm seed zone depth, as well as in the entire 180-cm soil profile, was not affected by tillage system (Schillinger, 2001). Therefore, CT held no agronomic advantages over MT or DMT in this experiment, but it did have distinct environmental disadvantages.

Profitability and Sensitivity Analysis

Variability in market net returns reflect different yields and production costs over the 5-yr experiment. As noted above, wheat prices were held constant over time and tillage system. For the 5-yr experiment, net returns over total costs for the three tillage systems were not statistically different at the 0.05 significance level (Table 3). Measured by net returns over variable costs, DMT was less profitable than the other two tillage systems at the 0.05 significance level. Based on the average prices and yields, market returns of all three tillage systems fell short of covering total costs by \$27 to \$40 ha^{-1}. Total costs include a wage for the operator, a land charge, machinery depreciation, interest costs, as well as variable input costs. Negative market net returns over total costs are fairly common in grain production when government payments are not included. In part, this is because the value of government payments are capitalized into land values, thus increasing costs. In the absence of government payments, land costs would decrease for owner operators, and market returns might more closely cover costs.

The results in Table 3 are based on average prices and yields; however, market prices and farm yields vary widely over time. For example, a 5-yr average price of \$144.02 Mg^{-1} for soft white wheat was used in this analysis, but wheat prices in the region fell sharply to \$88.18 and \$110.22 Mg^{-1} during 1998 and 1999, respectivley. Similarly, dryland wheat yields in this region vary substantially from year to year, as shown in Table 2. To illustrate the effect of price and grain yield variation on market net returns, Table 4 shows net-return sensitivity to different price and grain yield combinations for CT, MT, and DMT. Sensitivity results for MT, the most competitive conservation tillage system, are discussed here to illustrate the effects of price and yield variability. If MT wheat averages 4.03 Mg ha^{-1} and a price of \$146.96 Mg^{-1} is received, market returns over total costs equal \$9.83 ha^{-1}. Prices of \$128.59 Mg^{-1} or less are shown to generate losses before government payments for all yields of 4.37 Mg ha^{-1} or less (Table 4). Given the experiment's 1996 through 1999 average grain yield for MT of 3.89 Mg ha^{-1} (this yield falls between the discrete values in Table 4), one can compute that a price of \$147.19 Mg^{-1} is required to cover the total cost of

Table 3. Mean market net returns over variable and total costs per rotational hectare for winter wheat from 1995 to 1999 as affected by fallow tillage system.

Fallow tillage system	\$ ha^{-1} revenue	\$ ha^{-1} cost Variable	Fixed	Total	\$ ha^{-1} net returns over cost† Variable	Total
Conventional (CT)	247.73	144.34	130.66	275.00	103.39a	−27.27a
Minimum (MT)	259.67	155.69	130.59	286.29	103.97a	−26.62a
Delayed minimum (DMT)	245.56	157.52	124.24	281.76	88.03b	−36.21a

† Within-column mean net returns followed by the same letter are not statistically different at the 0.05 level.

Table 4. Market returns over total costs as affected by soft white winter wheat price and grain yield for three fallow tillage systems (positive net returns are highlighted in italic).†

	Wheat price, \$ Mg^{-1}					
Yield	**91.85**	**110.22**	**128.59**	**146.96**	**165.33**	**183.70**
$Mg\ ha^{-1}$	\$ ha^{-1}					
			Conventional (CT)			
1.68	−197.85	−182.42	−166.98	−151.55	−136.12	−120.69
2.02	−182.23	−163.68	−145.12	−126.57	−108.02	−89.46
2.35	−167.08	−145.49	−123.91	−102.32	−80.74	−59.15
2.69	−151.46	−126.75	−102.05	−77.34	−52.63	−27.92
3.03	−135.85	−108.02	−80.19	−52.36	−24.53	*3.31*
3.36	−120.69	−89.83	−58.97	−28.11	*2.75*	*33.62*
3.70	−105.08	−71.09	−37.11	−3.12	*30.86*	*64.84*
4.03	−89.92	−52.91	−15.89	*21.12*	*58.14*	*95.16*
4.37	−74.31	−34.17	*5.97*	*46.11*	*86.25*	*126.38*
4.71	−58.69	−15.43	*27.83*	*71.09*	*114.35*	*157.61*
			Minimum (MT)			
1.68	−209.14	−193.71	−178.27	−162.84	−147.41	−131.98
2.02	−193.52	−174.97	−156.41	−137.86	−119.31	−100.75
2.35	−178.37	−156.78	−135.20	−113.61	−92.03	−70.44
2.69	−162.75	−138.04	−113.34	−88.63	−63.92	−39.21
3.03	−147.14	−119.31	−91.48	−63.65	−35.82	−7.98
3.36	−131.98	−101.12	−70.26	−39.40	−8.54	*22.33*
3.70	−116.37	−82.38	−48.40	−14.41	*19.57*	*53.55*
4.03	−101.21	−64.20	−27.18	*9.83*	*46.85*	*83.87*
4.37	−85.60	−45.46	−5.32	*34.82*	*74.96*	*115.09*
4.71	−69.98	−26.72	*16.54*	*59.80*	*103.06*	*146.32*
			Delayed minimum (DMT)			
1.68	−204.61	−189.18	−173.74	−158.31	−142.88	−127.45
2.02	−188.99	−170.44	−151.88	−133.33	−114.77	−96.22
2.35	−173.84	−152.25	−130.67	−109.08	−87.50	−65.91
2.69	−158.22	−133.51	−108.81	−84.10	−59.39	−34.68
3.03	−142.61	−114.78	−86.95	−59.12	−31.29	−3.45
3.36	−127.45	−96.59	−65.73	−34.87	−4.01	*26.86*
3.70	−111.84	−77.85	−43.87	−9.88	*24.10*	*58.08*
4.03	−96.68	−59.67	−22.65	*14.36*	*51.38*	*88.40*
4.37	−81.07	−40.93	−0.79	*39.35*	*79.49*	*119.62*
4.71	−65.45	−22.19	*21.07*	*64.33*	*107.59*	*150.85*

† Returns reflect 0.5 ha of wheat and 0.5 ha of summer fallow. Total cost = \$275.00 per rotational ha for CT, \$286.29 for MT, and \$281.76 for DMT.

\$286.29 per rotational hectare. Table 4 shows that if grain yield for MT falls below 3.03 Mg ha^{-1}, as occurred in 1999 (Table 2), the farmer will fail to meet total costs from market sales even with the relatively high wheat price of \$183.70 Mg^{-1}.

CONCLUSIONS

Results from this 5-yr study show no statistical difference in grain yield among CT, MT, and DMT fallow systems. The three tillage systems were economically equivalent based on market returns over total production costs. The reduced tillage systems promise potentially greater future productivity by controlling wind erosion. Furthermore, the reduced-tillage systems lessen the risk of government payment denial due to inadequate residue for compliance. Economic analysis indicates that no or minimal subsidies should be needed to entice producers to switch from conventional to reduced-tillage fallow because the systems are equally profitable. This is especially true for the MT system, which had statistically equivalent profitability with CT for both net returns over variable and total costs. Because there is no significant short- or long-run economic sacrifice for converting to soil-saving MT fallow systems, they represent best management practices for both farmers and downwind urban dwellers. Extension education programs should highlight both the economic and conservation advantages of MT.

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