Reprinted from *Agronomy Journal*
Vol. 86, No. 4

Effectiveness and Economics of Dryland Conservation Tillage Systems in the Southern Great Plains

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ABSTRACT

Precipitation is limited in the Southern Great Plains, and farmers must minimize production costs and control erosion. The purpose of this research was to determine economic feasibility of dryland no- and reduced-tillage systems compared with sweep plowing on Pullman clay loam soil (fine, mixed, mesic Torrertic Paleustoll) in continuous winter wheat (*Triticum aestivum* L. emend. Thell) and in a winter wheat–sorghum [*Sorghum bicolor* (L.) Moench]–fallow rotation with two crops produced in 3 yr. Economic analyses considered 4-yr averages of income and treatment costs. In continuous winter wheat, sweep plowing yielded significantly less (425 kg ha^{-1}) than the best no-tillage treatment in 2 of 4 yr. Because of low variable costs, sweeping was most profitable in the short-term, and when machinery depreciation was considered for the long-term, sweep tillage followed by glyphosate lost the least money. In the fallow period between sorghum and wheat, sweep plowing yielded significantly less than the best no-tillage 2 of 4 yr or an average of 275 kg ha^{-1}. However, because of low variable costs, sweep plowing was the most profitable in the short run, \$84 ha^{-1}, but \$3 ha^{-1} less profitable in the long run than sweep plowing followed by glyphosate. In the wheat–sorghum part of the rotation, using paraquat or glyphosate alone resulted in lowest yields because of poor weed control. Sweep plowing yielded less than the best no-tillage 1 of 4 yr, but lower costs made it the most profitable, both short and long term.

THE WESTERN PART of the southern Great Plains is a windy, semiarid region where crop yields are low because of limited precipitation and high evaporation; thus, production costs must be minimized and soil must be protected from the constant threat of wind erosion. Wheat and grain sorghum are the predominant crops and are each grown on ≈5 million ha. About 33% of the land is irrigated from the slowly recharged Ogallalla aquifer, which is being depleted (Lansford et al., 1987; Musick et al., 1990). Under these conditions, conservation of precipitation is extremely important for both irrigated and dryland farming, in both the near term, to lower production costs, and in the future, to conserve a diminishing natural resource that controls the region's agricultural stability and prosperity. In addition, producers must develop farm plans that meet conservation compliance provisions of the 1985 Food Security Act (Federal Register, 1987).

Because this area was the center of the Dust Bowl in the 1930s and has experienced severe wind erosion, various systems of conservation tillage have been evaluated. Research has shown that crop residue on the soil surface not only controls erosion, but increases soil water storage in fallow (Greb et al., 1967; Unger, 1978). The most successful system is stubble mulch tillage with sweep plows having V-shaped blades operated ≈0.1 m deep to kill weeds while leaving most crop residues on the soil surface (Greb et al., 1970; Johnson and Davis, 1972). However, each operation with sweep plows destroys 20% of the stubble on the soil surface. Consequently, improved methods of conserving crop residues and controlling weeds have been sought. Early attempts to control weeds in fallow with herbicides in the Great Plains were referred to as chemical fallow (Baker et al., 1956; Wiese et al., 1960; Wiese et al., 1967), but were not successful; the weeds were not always controlled, and thus used valuable soil water. The first successful system, developed in 1964, used atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine] in conjunction with either 2,4-D (2,4-dichlorophenoxyacetic acid) or sweep plowing to control weeds in fallow between winter wheat and sorghum (Phillips, 1964, 1969; Wicks et al., 1969). Researchers also used this system to increase the efficiency of using irrigation water (Musick et al., 1977). In two reports, sorghum yield was increased up to 1000 kg ha^{-1} (Musick et al., 1977; Wiese and Unger, 1983). With this system, yield increase resulted from increased soil water storage in fallow with no-tillage systems that leave large amounts of crop residue on the soil surface (Unger, 1978; Unger and Wiese, 1979). These systems were very profitable compared with conventional tillage (Harman and Martin, 1987; Harman et al., 1989).

Dryland crop yields are lower than irrigated yields, and less crop residue remains to assist in water storage in fallow. Our objective was to develop conservation tillage systems that control weeds in two dryland crop rotations involving winter wheat and to evaluate their profitability compared with sweep plowing.

MATERIALS AND METHODS

This study was conducted at the USDA Conservation and Production Research Laboratory, Bushland, TX, on Pullman clay loam with 17 g kg^{-1} organic matter and pH 7.7. The two rotations were continuous hard red winter wheat ('Scout 66') with a 0.25-yr fallow period between crops, and winter wheat–sorghum ('Jacques 505')–fallow with a crop harvested in 2 of 3 yr and a 0.9-yr fallow period between crops. Continuous winter wheat treatments were applied to the same plots each year. The second rotation was broken into two parts: sorghum–fallow–wheat, and wheat–fallow–sorghum. Experiments were started each year in an adjacent area where the first crop in the rotation had just been harvested. In continuous wheat and wheat to sorghum, various no-tillage or reduced-tillage treatments were initiated on wheat stubble immediately after harvest and compared with sweep plowing for weed control during the fallow period. In sorghum to wheat, treatments were initiated in April following sorghum harvest the previous October and continued until wheat planting in late September. Wheat was planted with a drill having 25-mm-wide chisels, at 30 kg ha^{-1} in 250-mm rows. Sorghum was seeded with a no-tillage planter in mid June in 1-m rows at 3 kg ha^{-1}. All three experiments were started in 1987 and continued through 1991, when four crops had been harvested.

Pigweed (mixture of *Amaranthus palmeri* S. Watts and *A. hybridus* L.), Russian thistle (*Salsalo iberica* Sennen & Pau), kochia [*Kochia scoparia* (L.) Schrad.], tumble windmillgrass (*Chloris verticillata* Nutt.), tumblegrass [*Schedonnardus panic-*

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Published in Agron. J. 86:725-730 (1994).

Abbreviations: a.e., acid equivalent; a.i., active ingredient.

Table 1. Tillage and herbicide applications between crops and in continuous winter wheat.

Treatment no.	Treatment†	Herbicide rate	Tillage or herbicide applications 1987–1988	1988–1989	1989–1990	1990–1991
		g ha^{-1}	no.			
1	chlorsulfuron (July)	28	1	1	1	1
	glyphosate	426	3	3	3	2
	metsulfuron (Feb.)	5	–	–	1	–
2	chlorsulfuron (July)	28	1	1	1	1
	paraquat	560	2	2	2	2
	paraquat	1120	1	1	1	–
	metsulfuron (Feb.)	5	–	–	1	–
3	metsulfuron (July)	5	1	1	1	1
	glyphosate	426	3	3	3	2
	metsulfuron (Feb.)	5	–	–	1	–
4	sweep plowing (July)		1	1	1	1
	glyphosate	426	2	2	2	2
	metsulfuron (Feb.)	5	–	–	1	–
5	sweep plowing (fall)		1	2	1	1
	chlorsulfuron	28	2	1	1	1
	glyphosate	426	2	2	2	2
	metsulfuron (Feb.)	5	–	–	1	–
6	sweep plowing		3	3	4	4
	metsulfuron (Feb.)	5	–	–	1	–

† Metsulfuron was applied in early February 1990 to control flixweed in the wheat on all treatments.

ulatus (Nutt.) Treb.], and witchgrass (*Panicum capillare* L.) were most troublesome in fallow. Pigweed and witchgrass predominated in sorghum, and flixweed [*Descurainia sophia* (L.) Webb. ex Prant] infested wheat in 1 yr of 4.

Treatment operations are detailed in Tables 1, 2, and 3. Sweep plows were equipped with V-shaped blades that were 0.8 m wide. Glyphosate [*N*-(phosphonomethyl) glycine] and paraquat (1,1′-dimethyl-4,4′-bipyridinium ion) were applied in 132 L ha^{-1} of water containing 0.5% v/v nonionic surfactant, using flat fan tips and 207 kPa pressure. Ammonium sulfate was added to glyphosate sprays at 20 g L^{-1}. Other herbicides also were sprayed in 132 L ha^{-1} of water carrier, with surfactants added as suggested on herbicide labels.

Plots were 8 by 18 m. Treatments were replicated three times in randomized complete block arrangements. Data obtained were number of plowing or spraying operations, gravimetric soil water (sampled at 0.3-m increments to 1.2 m in the soil profile), and grain yield. Three soil water samples were taken per plot just before planting. Available soil water was calculated by subtracting soil water at the wilting point from total water in the soil samples. Grain yields were obtained using plot harvesters to cut two 1-m rows of sorghum and two 1.35-m swaths of wheat that were 18 m long. All data were subjected to analysis of variance; means were separated with Duncan's multiple range tests at $P = 0.05$.

Average grain yield along with costs of plowing and herbicide applications in fallow and in crops were used to make short- and long-term economic analyses. Total production costs were calculated for an owner-operator, including variable production costs and machinery depreciation, but excluding a management charge and land payment or rental expense. Machinery costs were obtained from 1990 enterprise budgets developed by the Texas Agricultural Extension Service (Anonymous, 1990). Herbicide costs that farmers would pay were obtained from a local farm cooperative in 1992. The grain target price in 1991 was used to calculate sales income. Analysis of variance of short- and long-term costs for each treatment were made using the four annual costs as replications, because tillage and spraying were done on a treatment rather than plot basis.

Table 2. Tillage and herbicide applications used in the 0.9-yr fallow and wheat crop from sorghum harvest to winter wheat harvest.

Treatment no.	Treatment†	Herbicide rate	Tillage or herbicide applications 1987–1988	1988–1989	1989–1990	1990–1991
		g ha^{-1}	no.			
1	chlorsulfuron (April)	14	1	1	1	1
	atrazine (April)	851	–	–	1	1
	glyphosate	426	3	1	3	1
	2,4-D	560	1	–	–	–
	2,4-D	1120	1	–	–	–
	metsulfuron + 2,4-D	2 + 851	1	–	–	–
	sweep plowing		1	–	–	–
2	chlorsulfuron (April)	28	1	1	1	1
	glyphosate	426	3	1	3	4
	2,4-D	560	1	–	–	–
	2,4-D	1120	1	–	–	–
	metsulfuron + 2,4-D	2 + 851	1	–	–	–
	sweep plowing		1	–	–	–
3	chlorsulfuron (April)	28	1	1	1	1
	paraquat	560	1	1	1	4
	paraquat	1120	2	–	2	–
	2,4-D	560	1	–	–	–
	2,4-D	1120	1	–	–	–
	metsulfuron + 2,4-D	2 + 851	1	–	–	–
	sweep plowing		1	–	–	–
4	chlorsulfuron (April)	28	1	1	1	1
	2,4-D	560	1	–	–	–
	sweep plowing		3	4	4	4
	metsulfuron + 2,4-D	2 + 851	1	–	–	–
5	glyphosate	426	4	3	3	4
	2,4-D	1120	1	–	–	–
	sweep plowing		1	–	–	–
	metsulfuron + 2,4-D	2 + 851	1	–	–	–
6	paraquat	560	2	1	1	4
	paraquat	1120	2	2	2	–
	2,4-D	1120	1	–	–	–
	sweep plowing		1	–	–	–
	metsulfuron + 2,4-D	2 + 851	1	–	–	–
7	sweep plowing		6	5	5	5
	metsulfuron + 2,4-D	2 + 851	1	–	–	–

† Metsulfuron and 2,4-D applied in early March 1988 on all treatments to control flixweed in the wheat.

Table 3. Tillage and herbicide applications used in the 0.9-yr fallow and sorghum crop from wheat harvest to sorghum harvest.

Treatment no.	Treatment†	Herbicide rate	Tillage or herbicide applications 1987–1988	1988–1989	1989–1990	1990–1991
		g ha^{-1}	no.			
1	atrazine (July)	3405	1	1	1	1
	2,4-D (July)	1120	1	1	1	1
	glyphosate	426	5	4	3	1
	propazine	1135	1	1	1	–
	sweep plowing		–	–	–	1
2	atrazine (July)	3405	1	1	1	1
	paraquat	560	1	3	2	–
	paraquat	1120	2	1	1	–
	propazine	1135	1	1	1	–
	sweep plowing		2	1	1	–
3	paraquat	560	1	5	1	2
	paraquat	1120	3	1	2	–
	propazine	2270	1	1	1	–
	sweep plowing		2	–	–	–
4	glyphosate	426	4	6	4	2
	propazine	2270	1	1	1	–
	sweep plowing		2	–	–	1
5	sweep plowing		6	5	6	4
	propazine	2270	1	1	1	–

† Propazine was applied preemergence to control weeds in sorghum in 1988, 1989, and 1990.

Continuous Winter Wheat

Herbicide treatments including rate of application and sweep plowings from 1987 through 1991 are in Table 1. In Treatments 1 and 2, chlorsulfuron {2-chloro-*N*-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]benzenesulfonamid} was either mixed with glyphosate at 426 g a.e. ha^{-1} or paraquat at 560 or 1120 g a.i. ha^{-1} for the initial treatment after wheat harvest. Rates of paraquat varied with weed size. Weeds that escaped or germinated after initial treatments were controlled with glyphosate or paraquat as indicated during the 0.25-yr fallow period. Metsulfuron {2[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino] carbonyl]amino]sulfonyl]benzoic acid} was the residual herbicide in Treatment 3, and was mixed with glyphosate to control existing weeds after harvest and glyphosate was used as needed on weeds that escaped or germinated later. In Treatment 4, one sweep plowing was done after harvest and glyphosate applications controlled weeds thereafter. This sweep plowing saved one application of glyphosate and a residual herbicide. In Treatment 5, glyphosate was used after harvest as needed, and one sweep plowing was done just before planting. The sweep plowing eliminated one glyphosate application. It was necessary in one of the years to use metsulfuron to control flixweed in the wheat crop. Three or four sweep plowings were needed to control weeds in the 0.25-yr fallow.

Sorghum to Wheat

Treatments used in the 0.9 yr fallow and in wheat are in Table 2. The first two treatments were chlorsulfuron at either 14 or 28 g a.i. ha^{-1} mixed with 2,4-D or glyphosate. In April, the first year, there were not any winter annual rescuegrass (*Bromus catharticus* Vahl) and downy brome (*Bromus tectorum* L.) in the sorghum stubble and 2,4-D at 560 g ha^{-1} was mixed with chlorsulfuron to control flixweed that germinated in the winter. There was not enough precipitation to activate chlorsulfuron, so 2,4-D at 1120 g ha^{-1}, was sprayed on all treatments except sweep plowing in May 1988. In the last 3 yr of the study, winter annual grass weeds infested the plots and glyphosate was mixed with chlorsulfuron with Treatments 1, 2, and 3. Atrazine at 840 g a.i. ha^{-1} was mixed with the low rate of chlorsulfuron the last 2 yr to increase herbicide residual in the soil. When glyphosate or paraquat were used to control weeds after initial treatment with chlorsulfuron, from one to three additional applications were required, depending on year. In the 1987–1988 fallow period, tumble windmillgrass and tumblegrass infested all plots, and after herbicide applications failed, one sweep plowing had to be performed. Comparing Treatments 4 and 5, the application of chlorsulfuron in April did not reduce the number of glyphosate applications needed on fallow. Treatments 5 and 6 compared glyphosate and paraquat alone during fallow. Three or four applications were used, but during dry times, paraquat at 1120 g ha^{-1} did not control weeds as well as glyphosate. It took five or six sweep plowings to control weeds on fallow. A mixture of 2,4-D and metsulfuron was used to control flixweed in wheat the first year of the study.

Wheat to Sorghum

The five treatments used in the 0.9 yr fallow are in Table 3. Basic treatments applied after wheat harvest in early July were atrazine at 3400 g a.i. ha^{-1} mixed with either 2,4-D, glyphosate, or paraquat, and glyphosate or paraquat alone. Four to six sweep plowings was the check. Sweep plowing was used once or twice in 2 of 4 yr on some treatments when control of tumblegrass and tumble windmill grass was not achieved with herbicides. Propazine [6-chloro-*N*,*N'*-bis(1-methylethyl)-1,3,5-triazine-2,4-diamine] at 1135 g a.i. ha^{-1} was used where atrazine had been used in the fallow, or at 2270 g ha^{-1} where atrazine had not been used in fallow for preemergence weed control in sorghum the first 3 yr, but application was accidently omitted the fourth year.

RESULTS

Continuous Winter Wheat

There was no difference in mean available soil water at planting among treatments (Table 4); however, there was a significant year × treatment interaction. In 1987 and 1988, there was less available soil water with sweep plowing than with chlorsulfuron plus glyphosate or metsulfuron plus glyphosate. In 1989, water storage with sweep plowing was equal to the best no-tillage treatment and was more than the no-tillage treatment where chlorsulfuron was mixed with paraquat. In 1990, soil water storage was similar with sweep plowing and no-tillage treatments, except that metsulfuron plus glyphosate had more stored soil water than other treatments.

Mean yield of continuous wheat was not affected by treatment, and yields in individual years did not follow the same pattern as available soil water at planting. Wheat yields were low 3 of 4 yr (Table 4). Precipitation during fallow and wheat crop (July through June, 1.0 yr) was 570, 425, 538, and 341 mm for wheat harvested in 1988, 1989, 1990, and 1991, respectively. The 51-yr mean precipitation

Table 4. Available water in the 1.2-m soil profile at planting of continuous winter wheat, and the subsequent wheat yield.

Treatment no.	Treatment	Herbicide rate	Available soil water					Wheat yield				
			1987	1988	1989	1990	4-yr mean	1988	1989	1990	1991	4-yr mean
		g ha^{-1}	mm					kg ha^{-1}				
1	chlorsulfuron (July) glyphosate	28 426	114a†	123a	128ab	22b	97A	750a	500a	1550a	790a	900A
2	chlorsulfuron (July) paraquat	28 560	90bc	111ab	119b	35ab	89A	240b	540a	1490a	960a	810A
3	metsulfuron (July) glyphosate	5 426	102ab	121a	123ab	50a	99A	670a	540a	1590a	970a	950A
4	glyphosate sweep plowing (July)	426	92bc	97b	139a	29b	89A	660a	300a	1780a	880a	910A
5	chlorsulfuron (July) glyphosate sweep plowing (fall)	28 426	89bc	105ab	124ab	28b	87A	690a	340a	1680a	750a	870A
6	sweep plowing		71c	98b	135a	29b	83A	580a	240b	1720a	420b	740A

† Within columns, means followed by the same letter are not significantly different according to Duncan's multiple range test ($P = 0.05$).

Table 5. Economic analyses for continuous winter wheat, wheat in the wheat–sorghum–fallow rotation, and sorghum in the wheat–sorghum–fallow rotation.

Treat-ment no.†	Income‡ Wheat	Income‡ Sorghum	Expenses: Herbicide and tillage	Expenses: Planting and seed	Expenses: Interest§	Expenses: Harvest and haul	Expenses: Total variable costs	Returns over variable costs	Machinery depreciation	Returns to land, management, and risk
	Short-term analysis (variable costs)								Long-term analysis (fixed costs)	
	$ ha^{-1}									
			Continuous wheat							
1	126a¶		84b	12	10	34	140	(14)#	21b	(35)#
2	113a		97a	12	11	34	154	(41)	21b	(62)
3	133a		73a	12	8	35	128	5	21b	(16)
4	127a		58c	12	7	35	112	15	26b	(11)
5	122a		76b	12	9	34	130	(9)	29ab	(38)
6	104a		31d	12	4	34	81	23	39a	(16)
			Sorghum–wheat (wheat yield)							
1	202a		87a	12	10	39	148	54	23b	31
2	204a		93a	12	10	38	153	51	23b	28
3	193ab		112a	12	12	37	173	20	23b	(3)
4	186ab		60b	12	7	37	116	70	43b	27
5	200a		88a	12	10	38	148	52	20b	32
6	162b		112a	12	12	36	172	(10)	21b	(31)
7	183ab		46b	12	6	37	101	82	53a	29
			Wheat–sorghum (sorghum yield)							
1		338a	110a	10	12	44	176	162	27b	135
2		343a	112a	10	12	45	179	164	29b	135
3		161b	129a	10	14	21	174	(13)	32b	(45)
4		218ab	114a	10	12	28	165	54	32b	22
5		328a	59b	9	7	43	118	210	58a	152

† Treatment numbers are detailed in Table 1 (continuous winter wheat), Table 2 (fallow and wheat in the wheat–sorghum–fallow rotation), and Table 3 (fallow and sorghum in the wheat–sorghum–fallow rotation).
‡ Wheat @ \$0.14 kg^{-1}; sorghum @ \$0.103 kg^{-1}.
§ Annual interest @ 10%.
¶ Within columns and rotations, means followed by the same letter are not significantly different according to Duncan's multiple range test ($P = 0.05$).
# Values in parentheses indicate negative returns.

value is 467 mm. Yields in 1988 were low, even though precipitation was above average. Rainfall was very low during April and May during grain filling. In 1988, chlorsulfuron plus paraquat followed by paraquat as needed, did not control weeds, and yield was only 240 kg ha^{-1} (compared with the best yield, 750 kg ha^{-1}, when chlorsulfuron was mixed with and followed by additional sprays of glyphosate). In 1989 and 1991, yield level was very low and sweep plowing resulted in yields lower than any no-tillage system. In 1990, yields were about twice as high as the other 3 yr and treatments had no effect.

Economic analyses (Table 5) were based on target price for average yields in Table 4 and costs averaged for 4 yr. Variable costs for no- and reduced-tillage treatments were about two to three times higher than sweep plowing, which was \$31 ha^{-1}. Highest variable cost for a reduced- or no-tillage treatment was \$97 ha^{-1} for chlorsulfuron plus paraquat and the lowest was \$58 ha^{-1} for sweep tillage followed by glyphosate as needed. Returns over variable costs for sweep plowing were \$23 ha^{-1}. Sweep plowing followed by glyphosate, the best reduced-tillage treatment, returned \$15 ha^{-1}. Losses were incurred for all other treatments except metsulfuron plus glyphosate.

In the long-term, considering machinery use and depreciation costs for the 4 yr, no treatments were profitable (Table 5). Machinery depreciation costs averaged \$39 ha^{-1} with sweep plowing, about \$21 ha^{-1} for treatments with no sweep plowing, and about \$26 ha^{-1} when one sweep plowing was used in conjunction with glyphosate. One sweep plowing followed by glyphosate as needed, minimized long-term losses to \$11 ha^{-1}. Metsulfuron plus glyphosate lost \$16 ha^{-1}, the same as sweep plowing. The highest loss treatment, chlorsulfuron plus paraquat, lost \$62 ha^{-1} long-term.

Sorghum to Wheat

Treatment affected available soil water at planting 2 of 4 yr, causing a significant treatment × year interaction, but had no effect on the 4-yr mean (Table 6). At planting in 1988, the chlorsulfuron plus glyphosate treatment resulted in more soil water than three other reduced- or no-tillage treatments, but was no better than sweep plowing. In 1990, differences were small, and chlorsulfuron plus paraquat resulted in more soil water than glyphosate or paraquat alone or sweep plowing; however, there was no consistent or logical effect of treatment on soil water storage in fallow.

In 3 of 4 yr, fallow and crop season precipitation exceeded the 51-yr mean of 636 mm (Table 6). Precipitation during fallow and wheat crop (November through June, 1.67 yr) was 865, 785, 672, and 565 mm for wheat harvested in 1988, 1989, 1990, and 1991, respectively. Mean wheat yield in this rotation is ≈ 1200 kg ha^{-1} at Bushland (Johnson and Davis, 1972). Although precipitation in the 1988–1989 fallow–crop season was above average, wheat yield was low in 1989 because of low rainfall in March, April, and May. Differences in available soil water at planting caused by fallow treatment did not have an effect on wheat yield.

Treatments used on fallow prior to planting affected wheat yield in 3 of 4 yr (Table 6). During Year 1, the best no-

Table 6. Available water in the 1.2-m soil profile at wheat planting and wheat yield in the wheat–sorghum–fallow rotation.

Treatment no.	Treatment	Herbicide rate	Available soil water					Wheat yield				
			1987	1988	1989	1990	4-yr mean	1988	1989	1990	1991	4-yr mean
		g ha^{-1}	mm					kg ha^{-1}				
1	chlorsulfuron (April) glyphosate	14 426	156a†	146a	133a	74ab	127A	1790ab	670a	1950a	1350a	1440A
2	chlorsulfuron (April) glyphosate	28 426	150a	133b	126a	66b	118A	1840ab	690a	1960a	1350a	1460A
3	chlorsulfuron (April) paraquat	28 560	137a	132b	133a	88a	123A	1880a	600ab	1610b	1430a	1380AB
4	chlorsulfuron (April) sweep plowing	28	156a	133b	130a	79ab	124A	1800ab	740a	1590b	1200a	1330AB
5	glyphosate	426	140a	139ab	133a	67b	120A	1810ab	670a	1910a	1330a	1430A
6	paraquat	60	138a	139ab	124a	58b	115A	1680ab	340c	1300c	1330a	1160B
7	sweep plowing		138a	137ab	142a	55b	118A	1600b	470bc	1930a	1250a	1310AB

† Within columns, means followed by the same letter are not significantly different according to Duncan's multiple range test ($P = 0.05$).

tillage treatment, chlorsulfuron followed by paraquat, resulted in higher yield than sweep plowing. Average mean yield where paraquat alone was used was lower than the two best no-tillage treatments. Otherwise, treatments did not consistently effect wheat yield.

Variable costs for no- and reduced-tillage treatments were greater than sweep plowing, except for Treatment 4, where chlorsulfuron applied in April was followed by sweep plowing (Table 5). Short-term costs per hectare for herbicides and spraying with no-tillage varied from \$87 to \$112, while sweep plowing cost \$46 ha^{-1}. Machinery depreciation was highest (\$53) for sweep plowing, but only \$23 ha^{-1} for no-tillage treatments. Thus, long-term returns to land, management, and risk for no-tillage ranged from a \$31 ha^{-1} loss for paraquat alone to \$32 profit where glyphosate was used alone in Treatment 5. Long-term profit with sweep plowing was \$29 ha^{-1}, about the same as the three best no-tillage treatments.

Wheat to Sorghum

Soil water samples were taken only the first 2 yr of the experiment (Table 7). In each of the 2 yr, less soil water was stored with sweep plowing than the best no-tillage treatment. Where paraquat was used alone, 2-yr soil water was less than with other treatments. Available water with other treatments, including sweep plowing, was not different. Precipitation during fallow and sorghum crop (July through October, 1.33 yr) was 785, 772, 615, and 638 mm for sorghum harvested in 1988, 1989, 1990, and 1991, respectively. The 51-yr mean precipitation value is 690 mm.

There was a significant year × treatment interaction for sorghum yield and differences among overall means (Table 7). Paraquat used alone resulted in lower 4-yr mean grain yield than sweep plowing or no-tillage where atrazine was used as a residual herbicide. The low yield for paraquat alone was the result of low soil water at planting and lack of weed control in the crop. In 1991, sweep plowing, paraquat alone, and glyphosate alone resulted in lower yields than atrazine followed by paraquat. This was caused in part by the fact that the crop was not cultivated or propazine not applied preemergence.

Economic analyses showed that sorghum grain (Table 5) produced more income than wheat (Table 5) in this 3-yr rotation. Based on target prices, income for wheat ranged from \$162 to \$204 ha^{-1}, while income from sorghum ranged from \$161 to \$343 ha^{-1}. In wheat to sorghum, short-term expenses for herbicides and spraying were almost twice as much for no-tillage treatments than for sweep plowing, which cost \$59 ha^{-1}. Short-term profit was \$210 ha^{-1} for sweep plowing, compared with \$164 ha^{-1} for atrazine plus paraquat, the most profitable no-tillage treatment. Although machinery depreciation for sweep plowing was about twice that for no-tillage, returns to land, management, and risk were \$17 ha^{-1} higher with sweep plowing than the best no-tillage systems.

These results are somewhat in conflict with other reports for the southern Great Plains, where various systems

Table 7. Available water in the 1.2 m soil profile at sorghum planting and sorghum yield in the wheat–sorghum–fallow rotation.

Treatment no.	Treatment	Herbicide rate	Available soil water			Sorghum yield				
			1988	1989	2-yr mean	1988	1989	1990	1991	4-yr mean
		g ha^{-1}	mm			kg ha^{-1}				
1	atrazine (July) glyphosate	3405 426	100abc†	136a	118AB	1830a	4280a	1870a‡	5150ab	3230A
2	atrazine (July) paraquat	3405 560	113a	128ab	121A	2060a	3890ab	1830a	5540a	3330A
3	paraquat	560	86b	121b	104B	1040b	3450b	1740a	0c	1560B
4	glyphosate	426	106ab	128ab	117AB	1870a	4190ab	1820a	610b	2120AB
5	sweep plowing		97bc	123b	110AB	2060a	3950ab	1810a	4900b	3180A

† Within columns, means followed by the same letter are not significantly different according to Duncan's multiple range test ($P = 0.05$).
‡ Yield for 1990 estimated as 20% of total dry matter; no grain because dry weather in May, June, and July of 1990 prevented planting until 30 July.

of no-tillage have increased yields as well as profits (Harman and Martin, 1987; Harman et al., 1989; Musick et al., 1977; Unger and Wiese, 1979; Wiese and Unger, 1983). However, in these cited publications, irrigation was involved on at least one of the crops, usually wheat, which increased the amount of straw on the soil surface and thus also enhanced soil water storage in fallow. This is in direct contrast to our dryland study, where only minimum amounts of straw were produced.

These results also are contrary to results from another dryland experiment at Bushland, TX, in which no- or reduced-tillage resulted in increased short- and long-term profit compared with sweep tillage (Jones et al., 1987). The most profitable system was using no-tillage in fallow between wheat and sorghum, followed by sweep plowing in fallow after sorghum. Differences between the two experimental sites were slope and weed spectrum. Slope where our studies were conducted was $\leq 0.5\%$, while slope at the other location was $\approx 1.5\%$. With more slope, modest residues on the soil surface may have increased soil water storage and yields. Also, tumble windmillgrass and tumblegrass infested the plots in our studies and were hard to kill with herbicides; this resulted in more applications of glyphosate and paraquat than used by Jones et al. (1987).

Economic analyses presented in this paper show high short-term costs with dryland no- or reduced-tillage systems, even though long-term profits were about equal with effective no-tillage systems or sweep plowing. Long-term profit is the basis of farm family survival, and we need to keep in mind that, over time, conservation tillage systems improve sustainability of agriculture.

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