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Managing Irrigated Winter Wheat Residues for Water Storage and Subsequent Dryland Grain Sorghum Production

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ABSTRACT

Better cropping and residue management systems are needed to improve precipitation-use efficiency, minimize ground water depletion by irrigation, reduce pumping costs, and conserve energy. An irrigated winter wheat (*Triticum aestivum* L.)-dryland grain sorghum [*Sorghum bicolor* L. (Moench)] cropping system was evaluated from 1972 to 1978 for water storage between wheat harvest and sorghum planting time and for subsequent grain sorghum growth and yields. No-tillage, sweep, and disk methods were used during the 11-month period between crops for wheat residue management and weed control. Precipitation stored as soil water during the 11 months of fallow averaged 35, 23, and 15%; available soil water contents to the 1.8-m depth at sorghum planting averaged 21.7, 17.0, and 15.2 cm; sorghum grain yields averaged 3,140, 2,500, and 1,930 kg/ha; and water-use efficiencies (WUE) for sorghum grain averaged 89, 77, and 66 kg/ha-cm for the respective treatments. Sorghum forage yields were slightly higher than grain yields and, therefore, WUE for forage production were higher than for grain. The WUE for forage, however, decreased in the same order as for grain. Based on March 1978 production costs and grain prices, net returns (excluding land, taxes, and interest costs) for sorghum production were four and two times greater with no-tillage and sweep tillage, respectively, than with disk tillage, the most widely used tillage method after irrigated wheat in the Southern Great Plains.

Additional Index Words: tillage, cropping systems, residue management, no-tillage, soil water use, grain quality, water-use efficiency, precipitation storage, weed control.

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ADEQUATE IRRIGATION results in higher yields than limited irrigation or dryland crop production. However, ground water for irrigation in the Southern Great Plains is being depleted because recharge to the aquifer is slight (Aronovici, 1971). Also, pumping costs have increased greatly in recent years because of rising energy costs. Hence, cropping systems are needed that make better use of precipitation, and depend less on irrigation.

A wheat (*Triticum aestivum* L.)-sorghum [*Sorghum bicolor* L. (Moench)]-fallow (WSF) cropping system, which provides for two crops in 3 years, is an

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adapted and widely used dryland cropping sequence in the western part of the Southern Great Plains. The WSF system, with 10 or 11 months of fallow after each crop, generally results in a higher percentage of the fallow-period precipitation stored as soil water than the wheat-fallow (WF) system, which has 15 or 16 months of fallow between crops in alternate years. With the WF system, little water is stored during the second summer after wheat harvest. Regardless of cropping system, soil profiles usually are not filled to field capacity by the end of fallow when disk or sweep tillage is used because precipitation stored as soil water with these tillage methods often ranges from only 15 to 25% in the Southern Great Plains (McCalla and Army, 1961; Unger, 1972).

Chemical fallow or no-tillage studies were started in the Great Plains in the 1950's. In these studies, herbicides were substituted for tillage to control weeds during fallow. Early results showed that chemical weed control was better than tillage for increasing water storage and dryland grain yields in the Central Great Plains (Phillips, 1964), but not in the Southern Great Plains (Army et al., 1961; Wiese and Army, 1958; Wiese et al., 1960, 1967). Later studies by Greb et al. (1967, 1970) suggested that a major reason for low water storage during fallow after dryland crops was the low residue production by these crops. They found that precipitation stored as soil water ranged from 16 to 26% with no residues to 31 to 37% with 6,720 kg/ha of wheat straw on the soil surface.

In the Southern Great Plains, residue production by dryland winter wheat and grain sorghum averages about 1,500 kg/ha. In contrast, these crops frequently produce from 6,000 to 10,000 kg/ha of residue when irrigated (Allen et al., 1975; Unger et al., 1971, 1973). When residues from irrigated wheat were maintained on Pullman clay loam [fine, mixed, thermic family of Torrertic Paleustolls (order Mollisols)] and weeds were controlled with herbicides, fallow-period precipitation stored as soil water was about 40 to 50%, as compared with 20% when the residues were incorporated with soil by tandem disking (Unger and Parker, 1975; Unger and Phillips, 1973; Unger et al., 1971). Extra water stored during fallow increased grain yields of nonirrigated sorghum (Unger and Parker, 1975) or sorghum irrigated with a limited amount of water (Unger and Phillips, 1973). Results were similar in Kansas when herbicides and one or two tillage operations were used for dryland grain sorghum (Phillips, 1969). When plots were adequately irrigated, yield differences resulting from chemical and tillage treatments were reduced (Musick et al., 1977).

For this study, an irrigated wheat-dryland grain sorghum rotation was used. Irrigated rather than dryland wheat was grown and wheat was planted after grain sorghum without an intervening fallow period. Irrigated wheat was used because of its high residue production potential. In this system, a wheat and a sorghum crop were produced in 2 years. The specific objectives were to evaluate effects of tillage, residue levels, and soil water content at wheat harvest on (i) soil water storage during fallow; (ii) subsequent grain sorghum growth and yields; (iii) growing-season water use and use efficiency by sorghum; (iv) sorghum grain quality; and (v) economics of tillage systems for grain sorghum production.

MATERIALS AND METHODS

The study was conducted from 1972 to 1978 on field plots at the USDA Southwestern Great Plains Research Center, Bushland, Texas, on a Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) with a 0.3% slope. Runoff from the plots was possible, but runon was prevented by low dikes at the upslope end of the plots. Based on $-1/3$ and -15-bar matric potentials, the soil has an available water storage capacity of about 23 cm to 1.8 m, the depth to which winter wheat with a well-developed root system can extract water.

So that both phases of the wheat-sorghum cropping system could be studied each year, the field was divided into two sets of plots. One set was in irrigated wheat and the other was in dryland grain sorghum each year. On each set of plots, the study had a randomized block, split-split plot design with two replications. There were two irrigation main plot treatments for obtaining different soil water contents at wheat harvest, two irrigation subplot treatments for obtaining different wheat residue production levels, and three tillage sub-subplot treatments for residue management and weed control during the 11-month fallow period between crops. On main plots (16 by 150 m), the last irrigation for wheat was applied either at early or late grain filling in an attempt to obtain differential soil water contents at the start of fallow.

Subplot treatments involved early spring irrigations for wheat. For one treatment, the first irrigation was applied when wheat began growing in the spring. For the other treatments, the first irrigation was delayed until the second irrigation for the early-irrigated wheat. Subplot size was 8 by 150 m.

Tillage treatments on the 8- by 50-m sub-subplots were tandem disking, sweep plowing, and no-tillage during fallow. Disk and sweep tillage were performed as necessary for weed and volunteer wheat control. For no-tillage, atrazine [2-chloro-4-(ethylamino-6-(isopropylamino)-*s*-triazine] and 2,4-D [propylene glycol butylether ester of (2,4-dichlorophenoxy) acetic acid] were applied at 3.4 and 1.1 kg/ha, respectively, soon after wheat harvest.

Before the study was started, the plot area was uniformly cropped to furrow-irrigated wheat. After wheat harvest in 1972, half the area was uniformly tandem disked, sweep plowed about 7 cm deep, and disk bedded. Before planting wheat, anhydrous ammonia at 168 kg N/ha was chiseled into the furrows. No additional fertilizer was applied for the subsequent grain sorghum crop. Wheat and grain sorghum have not responded to phosphorus and potassium fertilizers on Pullman clay loam (Mathers et al., 1975).

In the fall of 1972, 'Tamwheat 101' wheat was planted at 70 kg/ha on 1-m spaced beds and furrows with a drill having single-disk openers spaced at 25 cm. The procedure in 1973 for the second half of the study area was similar to that in 1972. In subsequent years, wheat was planted as soon as sorghum could be harvested and cultural operations could be performed. Operations after sorghum included two tandem diskings, disk bedding, fertilizing with anhydrous ammonia, and bed cultivation with a rolling cultivator. Wheat planting dates after sorghum ranged from 6 October to 22 November.

In addition to the emergence irrigation and the early- and late-season irrigation treatments, the wheat was furrow irrigated as needed to avoid plant water stress during the growing season. These irrigations ranged from one to four per wheat crop and averaged 3.3 per crop.

Near wheat maturity, plant samples were cut by hand near the ground level from 1-m^2 areas per plot for determining total dry matter yields. Wheat grain was harvested from plots with a field combine. The difference between total dry matter and grain yield was residue yield. All wheat yields are based on an air dry basis. Harvest dates ranged from 25 June to 10 July. After wheat harvest each year, tillage treatments were initiated when weeds needed control, and plots remained fallow about 11 months until grain sorghum planting the next spring. Herbicides in no-tillage plots effectively controlled weeds during fallow and the subsequent grain sorghum growing season. In disk and sweep plots, terbutryn [2-(*tert*-butylamino)-4-(ethylamino)-6-(methylthio)-*s*-triazine] was applied at 1.8 kg/ha before or after planting if needed for weed control in the sorghum.

Sorghum planting dates ranged from 23 May to 1 June. The sorghums (DeKalb 'C42C' in 1974 and 1975; 'C42Y+' in 1976 and 1977) were medium-maturity hybrids, and 'C42Y+' was greenbug [*Schizaphis graminum* (Rondani)] tolerant. Sorghum was planted in 1-m spaced rows to obtain about 96,000 plants/ha with planters having double-disk openers. The sorghum was flat-planted in disk and sweep plots and on intact beds in no-tillage plots. Surface residues were estimated at sorghum planting. In 1976 and 1977, the disk and sweep plots were cultivated for weed control.

Sorghum grain and forage yield samples were hand-harvested from four 3-m-long row sections in each plot. Grain yields were adjusted to 13.5% moisture. Forage samples were oven-dried at 60°C, and yields were reported as dry matter.

Soil cores for gravimetric water content determinations were obtained by 30-cm increments to the 1.8-m depth at two sites per plot at wheat harvest, sorghum planting, and sorghum harvest each year. During the sorghum growing season, soil water contents were monitored by the neutron-scattering technique at two locations in each plot on which wheat did not receive irrigation at late grain filling. The water contents were determined to the 1.2-m depth at about 2-week intervals, except in 1974 when weekly determinations were made early in the season. Precipitation was measured near the plot area.

RESULTS AND DISCUSSION

Wheat Residue Yields and Soil Water Contents at Wheat Harvest

Irrigation treatments for wheat did not cause statistically significant residue yield and water content differences because of interference from precipitation. Residue yields averaged 8,900, 4,800, 7,500, and 6,400 kg/ha in 1973, 1974, 1975, and 1976, respectively. Available soil water contents at wheat harvest averaged 8.0, 4.2, 13.5, and 6.5 cm to the 1.8-m depth in the respective years. Since residue yield and soil water content differences due to irrigation treatments were not significant in any year, only tillage treatment values are shown in the tables.

Weed Control and Surface Residues

Atrazine and 2,4-D controlled volunteer wheat and broadleaf weeds in no-tillage plots during fallow, but some grassy weeds and volunteer sorghum plants were observed in some years. These plants were too widely scattered to warrant control, except in the 1976-77 fallow when volunteer sorghum plants were controlled with 1.7 kg/ha of glyphosate [*N*-(phosphonomethyl) glycine]. Apparently, tillage after each sorghum crop and immediate cropping to irrigated wheat aided weed control. In Kansas, atrazine applied after dryland wheat failed to control grassy weeds (Phillips, 1969).

Atrazine applied after wheat harvest controlled volunteer wheat and broadleaf weeds into the sorghum growing season the next summer. Since the no-tillage plots were not plowed, an estimated 50 to 70% of the wheat residue remained on the surface at sorghum planting, and considerable amounts were still present at sorghum harvest.

In sweep plots, three to seven tillage operations were necessary during fallow. Three or four operations were necessary in disk plots. Tillage reduced the wheat residue remaining on the surface at sorghum planting to 30 to 50% of original amounts in sweep plots and to less than 10% in disk plots.

Precipitation, Precipitation Storage, and Available Soil Water at Sorghum Planting

Total precipitation averaged 4 cm below the long-term average during fallow and 1 cm above during the sorghum growing season (Table 1). Fallow-period precipitation stored as soil water was significantly higher for no-tillage than for the sweep and disk treatments (Table 2), which were in the range reported for stubble mulch and clean tillage methods for the Southern Great Plains (McCalla and Army, 1961; Unger et al., 1971). Greater storage with no-tillage resulted from greater amounts of surface residue, which increase infiltration and reduce evaporation (Unger, 1978). The large variations in the percentage of precipitation stored among different fallow periods, especially for no-tillage and sweep tillage treatments, resulted from differences in soil water contents at wheat harvest, and total precipitation and its distribution during fallow. When water contents are low at the start of fallow, the potential for storing precipitation is high, and vice versa.

Available soil water at sorghum planting (Table 2) consisted of water in soil at wheat harvest and that stored during fallow. No-tillage significantly increased precipitation storage, and available water contents at sorghum planting approached the field capacity of 23 cm for the 1.8-m depth each year. In 1974 and 1977, soil water content for the disk treatment was significantly lower than for the sweep treatment.

Sorghum Emergence and Growth

Favorable soil water conditions in the seed zone and rainfall soon after planting resulted in favorable germination, emergence, and plant populations in all plots

Table 1—Precipitation during the months of fallow and sorghum growing season.

Period	Month of fallow or sorghum growing season												
	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	Total
	mm												
Fallow 1973-74	–	35	36	28	28	1	3	7	11	45	0	84	278
Fallow 1974-75	1	35	220	49	104	4	11	9	20	5	30	30	518
Fallow 1975-76	–	64	26	16	0	35	5	0	3	15	62	38	264
Fallow 1976-77	–	35	54	63	36	9	0	5	11	19	37	68	337
Study average	–	42	84	39	42	12	5	5	11	20	32	55	347
Average 1939-1977	–	67	70	42	42	18	14	10	12	17	29	67	388
Sorghum GS† 1974	31	35	220	49	104	4							443
Sorghum GS 1975	58	64	26	16	–	–							164
Sorghum GS 1976	23	35	54	63	–	–							175
Sorghum GS 1977	54	7	199	10	6	–							276
Study average	42	35	125	35	–	–							265
Average 1939-1977	74	67	70	42	42	18							252‡

† GS—growing season.
‡ June through Sept. only.

Table 2—Precipitation stored as soil water, available soil water at sorghum planting, and soil water changes during the sorghum growing season for various tillage methods.

Period or year	Tillage method: No-tillage	Sweep	Disk
	Fallow-period precipitation stored—%		
1973-74	44.9 a†	30.0 b	16.1 c
1974-75	24.1 a	19.3 b	17.4 b
1975-76	26.3 a	15.0 b	13.8 b
1976-77	45.3 a	26.3 b	13.4 c
Average	35.2 a†	22.7 b	15.2 b
	Available soil water at planting—cm‡		
1974	20.8 a	15.9 b	12.5 c
1975	22.5 a	20.3 b	20.2 b
1976	20.8 a	17.3 b	17.0 b
1977	22.5 a	14.4 b	11.2 c
Average	21.7 a	17.0 b	15.2 b
	Growing-season soil water change—cm‡		
1974	+ 3.3 a	+ 4.9 a	+ 2.9 a
1975	−12.7 a	−11.8 a	−11.9 a
1976	− 8.9 a	− 6.7 b	− 5.5 b
1977	−15.8 a	− 9.9 b	− 7.5 c
Average	− 8.5 a	− 5.9 a	− 5.5 a

† Row values followed by the same letter are not significantly different at the 5% level (Duncan's Multiple Range Test).
‡ Determined to the 1.8-m depth. Plant available water storage capacity is 23 cm and the soil contains about 35.8 cm at −15 bars matric potential. Most water remaining in soil at harvest was at the 1.2- to 1.8-m depth, the depth from which sorghum uses little water on Pullman clay loam (Musick and Sletten, 1966).

each year. Because of favorable conditions at or soon after seedling emergence, early plant growth was not affected by tillage treatment in any year. Significant height differences, however, developed because of water stress in 1974, 1976, and 1977 (Fig. 1). No height measurements were made during the 1975 growing season because no differences were observed.

In 1974, significant height differences due to tillage treatment developed by 17 July. Abundant rainfall in August resulted in some additional height increases, which were primarily caused by axillary tiller development on water-stressed plants, especially on the more severely stressed plants in disk and sweep plots.

At the first measurement on 6 July 1976, height differences among all treatments were significant. Thereafter, plant heights in disk and sweep plots were similar, but significantly lower than in no-tillage plots.

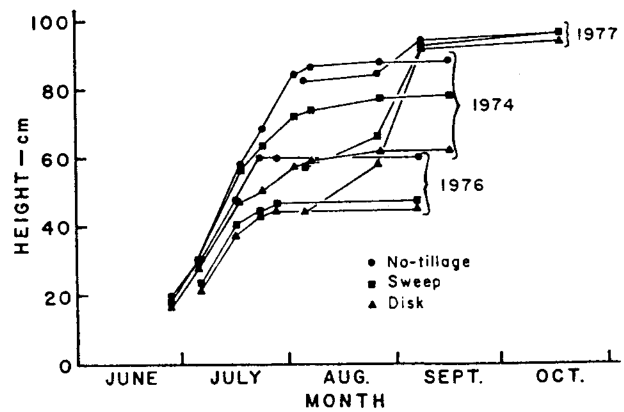

Fig. 1—Tillage effects on grain sorghum plant heights in 1974, 1976, and 1977.

Table 3—Effect of tillage method on sorghum grain and forage yields, and water-use efficiency.

Year	Tillage method: No-tillage	Sweep	Disk
	Sorghum grain yield—kg/ha		
1974	5,260 a†	4,070 b	2,930 c
1975	1,700 b	1,890 a	1,440 c
1976	2,640 a	2,190 b	2,140 b
1977	2,970 a	1,830 b	1,200 c
Average	3,140 a	2,500 ab	1,930 b
	Sorghum forage yield—kg/ha		
1974	5,060 a	4,220 b	3,620 b
1975	2,770 a	2,550 b	2,580 b
1976	3,800 a	2,670 b	2,640 b
1977	3,110 a	2,090 b	1,360 c
Average	3,690 a	2,880 b	2,550 b
	Water-use efficiency (grain)—kg/ha-cm‡		
1974	127.8	102.9	87.1
1975	58.3	66.9	50.8
1976	100.0	90.5	93.1
1977	68.4	48.8	34.2
Average	88.6	77.3	66.3
	Water-use efficiency (forage)—kg/ha-cm‡		
1974	123.0	106.7	87.1
1975	95.1	90.3	91.0
1976	144.0	110.4	114.8
1977	71.7	55.7	38.8
Average	108.5	90.8	83.0

† Row values followed by the same letter are not significantly different at the 5% level (Duncan's Multiple Range Test).
‡ Based on kilograms grain or forage produced per ha-cm of precipitation and soil water change during the sorghum growing season.

Plants reached maximum height by late July and limited rainfall in August had no effect.

Major height differences had developed at the first measurement on 5 Aug. 1977. Above-average August rainfall resulted in renewed growth, especially of plants in disk and sweep plots. In contrast to 1974, axillary tillers grew taller than the main plants in 1977 and by early September plant heights in all plots were similar.

Sorghum Yields and Quality

Grain and forage yields were significantly affected by tillage methods each year. No tillage resulted in the highest yields, except for grain in 1975 (Table 3). Higher yields with no-tillage resulted from higher soil water contents at planting and from greater use of the additional stored water (Table 2, Fig. 2). A contributing factor probably was more efficient use of growing-season precipitation through increased infiltration and reduced evaporation due to more wheat residues on the surface. Generally higher soil water contents throughout the growing season (Fig. 2) reduced the severity of water stress in plants in no-tillage plots, which permitted better plant development as reflected by plant heights (Fig. 1) and forage yields (Table 3). These plants, therefore, had better-developed heads with the potential for producing more grain than the more severely stressed plants in sweep and disk tillage plots.

Grain yields were highest in 1974, even though yield prospects in disk and sweep tillage plots seemed poor during July due to severe water stress. The above-average August rainfall was timely for grain filling on main plants of no-tillage plots and yields were excellent for dryland sorghum. Much of the grain in sweep and disk plots, and some in no-tillage plots, was produced on axillary tillers that developed after the start of August rainfall. Average rainfall in September and above-average rainfall in October permitted good grain filling by tiller heads. Although tillers delayed maturity and harvest was not possible until after frost in November, grain yields were well-above the long-term average of 1,740 kg/ha for dryland grain sorghum in a conventional wheat-sorghum-fallow rotation (Unger, 1972). The grain yields for all treatments, however, compared favorably with those for similar treatments in 1972 when growing season rainfall was above average also (Unger and Parker, 1975).

No-tillage failed to increase grain yields in 1975 because of similar water contents at planting (Table 2) and favorable rainfall during June and July (Table 1). Also, potential yield differences in 1975 were limited by a severe uncontrolled greenbug infestation which contributed to the generally low yields.

In 1976, yields were significantly higher with no-tillage than with sweep and disk tillage, which resulted in similar yields.

Low water contents at planting in 1977 (Table 2) and much below average rainfall in July (Table 1) resulted in severe water stress and poor plant growth in sweep and especially in disk plots. As in 1974, above-average rainfall in August 1977 was timely for grain filling and good yields in no-tillage plots. The August rainfall also increased plant growth in sweep and disk tillage plots (Fig. 1) and undoubtedly improved grain yields. While high test weights and weights per 1,000 grains (Table 4) indicated good grain filling, early stress greatly reduced head size on the main plant and axillary tillering was less than in 1974.

Grain protein contents within years were generally inversely proportional to grain yields. An exception, for unknown reasons, occurred in 1976 when yield and protein content were lowest for the disk treatments.

Growing-Season Soil Water Changes

Soil water changes to the 1.8-m depth during the sorghum growing season are shown in Table 2. In Fig. 2, available water contents for portions or all of the different growing seasons are shown by 0.3-m increments to the 1.2-m depth, the depth to which sorghum normally uses water on Pullman clay loam (Musick and Sletten, 1966).

The greater amounts of water in no-tillage plots than in sweep and disk plots at sorghum planting (Table 2) were contained mostly in the upper 0.9 m of soil, except in 1977 when the water content in no-tillage plots was also greater at the 0.9- to 1.2-m depth increment (Fig. 2) and in 1975 when water contents were similar for all treatments at the first determination. Even though water use was greater from no-tillage plots, water content in these plots remained higher throughout most of the season. Because of this, sorghum in no-tillage plots experienced less water stress, responded more to limited rainfall, and, consequently, yielded more than in sweep and disk tillage plots.

In 1974 and 1977, sorghum in no-tillage plots used 1 and 2 cm of water, respectively, from the 0.6- to 0.9-m depth increment, whereas sorghum in sweep and disk plots used little water from this depth. At the 0.9- to 1.2-m depth, slight gains in soil water were noted in 1974. In 1977, however, water was used from this depth in no-tillage plots, but the soil gained water in sweep and disk plots. In 1975 and 1976, when growing-season rainfall was considerably below average, sorghum used water from all depths, regardless of tillage.

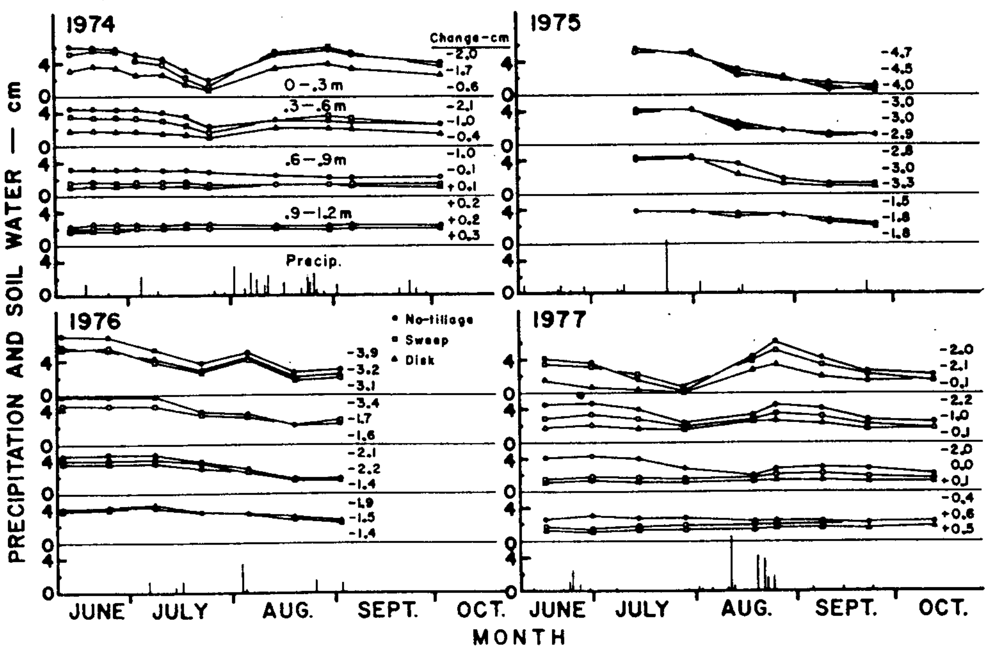

Fig. 2—Tillage effects on plant soil water contents by depth increments during the sorghum growing seasons. Seasonal soil-water changes for different depths are shown by values at the curves (*upper* — no-tillage; *middle* — sweep; *lower* — disk). Precipitation amounts are shown by vertical lines at the bottom of each part of the figure.

Water-Use Efficiency

Trends in water-use efficiency (WUE), based on kilograms of grain or forage produced per hectare-centimeter of water used (growing-season precipitation plus soil water use), generally followed grain or forage yield trends (Table 3). The WUE differences among treatments were small for grain in 1975 and 1976 when sorghum with all treatments experienced water stress because of below-average rainfall during the growing season. In 1974 and 1977, when rainfall was above average during at least part of the growing season, WUE differences among treatments were large.

As for grain, WUE differences among treatments were small for forage in 1975, but were large in other years (Table 3). Treatment values generally were slightly larger for forage than for grain. A major exception was in 1976, when the differences due to tillage were large for forage relative to grain. The much higher WUE for forage than for grain indicated that grain filling was hindered for no-tillage as compared with the other treatments. This was further indicated by the low grain weights with no-tillage in 1976 (Table 4). Incomplete grain filling with no-tillage in 1976 undoubtedly resulted from the larger plants (Fig. 1, Table 3), which experienced greater late-season water stress than the smaller plants in other plots.

Wheat after Sorghum

While this study emphasized soil water storage during fallow and grain sorghum production, some comments about the following wheat crop seem appropriate. Immediately after sorghum harvest, the entire plot area was uniformly disked, listed, fertilized, planted to wheat, and irrigated (if necessary) for wheat emergence.

Because sorghum was not harvested until after frost in 1974, wheat was not planted until 22 November, which is about 6 weeks later than optimum for irrigated wheat. This wheat yielded only 2,280 kg/ha of grain. There were no significant differences in wheat yields due to tillage for the previous sorghum crop.

More timely wheat planting on 6 Oct. 1975 resulted in above-average grain yields of 4,240 kg/ha for the 1975-76 crop. Again, tillage for sorghum had no effect on wheat yield. The 1976-77 wheat crop was also planted on 6 October, but yields were low in 1977 because prolonged cold weather immediately after planting delayed emergence until after 1 Jan. 1977. Grain yields were 1,470 and 1,420 in sweep and disk plots, respectively. Even lower yields with no tillage (710 kg/ha) resulted from atrazine carryover, which also resulted in low yields with no-tillage for the 1977-78 crop. Yields in 1978 were 2,270, 3,560, and 3,900 with no-tillage, sweep, and disk treatments, respectively. Normally, residual levels of atrazine are too low to affect susceptible crops after two summer periods. However, below-average rainfall during the summers of 1975, 1976, and early 1977 may have slowed degradation of atrazine. Also, the high application rate of atrazine (3.4 kg/ha) may have contributed to the carryover. When Wicks et al. (1969) applied atrazine at 2.2 kg/ha in a WSF rotation, no carryover effect on wheat was noted. The time from atrazine application to wheat planting was about 26 months in the study by Wicks et al. as compared with about 15 months in our study.

When sorghum harvest is delayed by wet fall conditions or date of maturity of tiller heads, immediate tillage and planting to irrigated winter wheat may not be desirable. Late-planted wheat that fails to develop tillers in the fall has a low yield potential. Other practices like the conventional WSF system increase wheat production reliability. This system has a fallow period after each crop, but permits only two crops in 3 years. Where land is more abundant than water, as in most of the Great Plains, the conventional WSF system should result in favorable irrigated wheat yields and above-average dryland sorghum yields when no-tillage is used during fallow after wheat. The extra time from atrazine application to wheat planting

Table 4—Sorghum grain quality as affected by tillage method.

Year	Tillage method: No-tillage	Sweep	Disk
		Grain test weight, g/liter	
1974	725 a†	711 b	682 c
1975	702 a	703 a	698 a
1976	763 a	767 a	763 a
1977	844 a	813 b	811 b
Average	759 a	749 a	739 a
		Grain weight, g/1,000 grains	
1974	22.4 a	21.7 b	20.0 c
1975	14.4 a	14.9 a	14.8 a
1976	18.2 b	20.6 a	19.1 ab
1977	26.4 a	25.6 a	22.1 b
Average	20.4 a	20.7 a	19.0 a
		Grain protein content, %	
1974	10.1 c	10.9 b	11.5 a
1975	14.9 b	14.7 b	15.9 a
1976	14.7 a	14.1 b	13.6 b
1977	14.1 c	15.7 b	17.2 a
Average	13.5 a	13.9 a	14.7 a

† Row values followed by the same letter or letters are not significantly different at the 5% level (Duncan's Multiple Range Test).

Table 5—Production inputs and yield for the grain sorghum crop as affected by tillage method.

Factor, period, and items	Avg. number or units per ha	Unit
Production input		
Fallow period		
Herbicides: (no-tillage plots)		
Atrazine	3.4	kg
2,4-D	1.1	kg
Glyphosate (1 yr only)	0.43	kg
Tillage—sweep	4.75	operation
—disk	3.75	operation
Sorghum growing season		
Herbicides:		
Terbutryn (sweep and disk plots)	1.8	kg
Fertilizer (33% of N applied to wheat)	56	kg
Seed	3.7	kg
Planting	1	operation
Cultivating (sweep and disk plots)	0.5	operation
Controlling insects (1 yr only)	0.25	operation
Harvesting (combining and hauling)	1	operation
Yield		
Grain—no-tillage	3,140	kg
—sweep	2,500	kg
—disk	1,930	kg

would also reduce the possibility of carryover damage from atrazine.

Economics

Tillage, fertilizer, planting, and harvesting practices for wheat were uniform for the plot area and differential irrigation treatments had no significant effects on wheat residue production and soil water contents at the start of fallow. Wheat yields after no-tillage grain sorghum were lower in 1977 and 1978 than with sweep and disk tillage, but such yield reduction would not be expected with the conventional WSF system. Therefore, production costs and returns for wheat under normal conditions should be similar regardless of tillage methods during fallow before grain sorghum. Hence, this economic analysis was limited to expenses during fallow and the sorghum crop, and to income from sorghum grain. Fixed expenses for land, taxes, and interest for borrowed capital were not included.

Monetary values, based on the production inputs and yields shown in Table 5, were calculated for prices prevailing at Bushland, Texas, in March 1978. The monetary values are not shown because of their variability due to location and time, but interested persons can readily determine them by applying prevailing prices to the input and yield items in Table 5.

Expenses during fallow were highest with no-tillage, primarily because glyphosate was applied 1 year to control volunteer sorghum plants (Table 5). Under practical farming conditions, these volunteer plants could have been controlled by one sweep plowing. While sweep plowing would disturb the residues, little or no effect on water storage would be expected (Unger et al., 1971). The sweep treatment was the next most expensive during fallow because an average of 4.75 tillage operations were required per year compared with 3.75 for the disk treatment. When glyphosate were not used, costs were lower for no-tillage than for sweep and disk tillage.

Although highest during fallow, total expenses were lowest for no-tillage. Total expenses were highest for sweep tillage. The shift in total expenses resulted from the use of terbutryn for controlling weeds in the sorghum crop in sweep and disk plots. In no-tillage plots, atrazine applied at the start of fallow also controlled weeds in the sorghum.

The analysis showed that no-tillage would have been the most profitable practice, even if grain yields had not been higher. However, higher yields with no-tillage greatly increased net income. Based on March 1978 values, net income with sweep and disk tillage was one-half and one-fourth, respectively, that with no-tillage. Disk tillage is commonly used for weed and volunteer control after irrigated wheat under conventional farming practices. Even though fixed costs and interest would decrease net income, the decrease would be similar for all tillage methods. No-tillage, therefore, would remain the most profitable system.

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