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Long-Term Effects of No-tillage in a Winter Wheat (*Triticum aestivum*)-Sorghum (*Sorghum bicolor*)-Fallow Rotation[1]

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Abstract. **This research was conducted near North Platte, NE, over an 18-yr period to determine the feasibility of using herbicides to replace tillage as the weed control method in a winter wheat (*Triticum aestivum* L.)-sorghum [*Sorghum bicolor* (L.) Moench.]-fallow rotation. Five tillage treatments [two tillage and three reduced or no-till treatments] were used on the same plots during the duration of this experiment on a Holdrege silt loam (Typic Argiustolls). Herbicides effectively replaced tillage for weed control. The no-till plots treated with atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine] after wheat harvest had higher sorghum and winter wheat yields, higher crop residue remaining on the soil surface, and lower weed yields than tilled plots. The most difficult weeds to control were volunteer wheat and barnyardgrass [*Echinochloa crus-galli* (L.) Beauv. #[3] ECHCG]. Soil surface pH decreased over time because of increased use of nitrogen. The pH in nontilled plots was significantly lower than in tilled plots due to lack of soil mixing. Exchangeable calcium was the predominant cation leached from the top 5 cm but showed accumulation between the 5- to 12.5-cm depth. Organic matter content showed little change over time.**

Additional index words: **Ecofallow, ecofarming, weed management, *Triticum aestivum* L., *Sorghum bicolor* (L.) Moench.**

INTRODUCTION

The winter wheat-sorghum-fallow rotation is a popular rotation in the Central Great Plains of the United States (23). Phillips (19) in Kansas initially reported the successful implication of a minimum-tillage system in this rotation. Later, the practice was introduced in Nebraska (33) and now thousands of hectares of corn (*Zea mays* L.) and sorghum are planted no-till into winter wheat stubble. This practice has been termed ecofarming (2) and is defined as a system of controlling weeds with herbicides and managing crop residues throughout a crop rotation with minimum use of tillage. This reduces soil erosion and production costs, while increasing weed control, water infiltration, water conservation, and crop yields. The fallow period between wheat harvest and planting of a crop the next spring is called ecofallow.

The initial benefits of using herbicides in place of tillage in the Central Great Plains have increased nonirrigated sorghum or corn yields (19, 27, 33). This yield increase was due to increased water storage during the ecofallow period when herbicides rather than sweep tillage were used to control weeds (27, 32). Soil water storage was also increased with increasing amounts of wheat straw mulch (13).

Other benefits have been less stalk rot [*Fusarium moniliforme* (Sheld.)] (8), erosion control (7), and savings of energy (14, 35) and labor (36). Cultivar selection, stand establishment, plant residue distribution, nutrient availability, and pests including weeds have been identified as potential problems in this minimum-tillage system (36).

Long-term investigations in the Great Plains comparing effects of management systems within the winter wheat-sorghum-fallow rotation on weed control and soil properties have not been reported in the literature. A long-term investigation (18 and 19 yr on two soils) in Ohio showed substantial changes in profile distribution of organic C, P, N, and pH for the 0- to 30-cm depths (5). Similar changes were noted in Kentucky (1), Georgia (28), and Nebraska (22). Decline in weed species through various management systems under irrigation have been reported (4, 25, 26). Weed species changes have occurred under minimum tillage in nonirrigated situations in the Great Plains. With annual use of atrazine, populations of kochia [*Kochia scopia* (L.) Schrad. # KCHSC] and redroot pigweed (*Amaranthus retroflexus* L. # AMARE) declined and green foxtail [*Setaria viridis* (L.) Beauv. # SETVI] and witchgrass (*Panicum capillare* L. # PANCA) increased (21). Annual grass weed species that have been reported to be difficult to control in an ecofarming system include foxtail spp. (*Setaria* spp.), field sandbur (*Cenchrus incertus* M. A. Curtis # CENIN) (20, 21), and barnyardgrass (15).

The objectives of this research were to determine the feasibility of herbicides replacing tillage in a winter wheat-grain sorghum-fallow rotation and the effects of 18 yr of no-tillage on nonirrigated crop production and soils in the Central Great Plains.

MATERIALS AND METHODS

This experiment was initiated at North Platte, NE, in 1962 on a Holdrege silt loam (fine-silty, mixed, mesic Typic Argiustolls) containing 1.6% organic matter, 28% sand, 52% silt, and 19% clay with a pH of 7.2 in the surface 15 cm. In 1962, a sorghum field was divided into three strips. Each strip represented 1 yr of a winter wheat-sorghum-fallow rotation. Sorghum was planted in one strip, proso

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[3]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32, Suppl. 2. Available from WSSA, 309 West Clark Street, Champaign, IL 61820.

Table 1. Treatment designations and sequence operations for the 3-yr rotation over the 18 yr at North Platte, NE. Herbicides listed are those that were used during the final 12 yr.

	July 15 to Nov. 1	April 1 to May 15	May 16 to Oct. 20	April 1 to Sept. 15
Treatment[a]	Winter wheat stubble		Sorghum	Fallow
A	Sweep plow twice	Tandem disk and harrow twice	Cultivate + 2,4-D 0.3 kg/ha	Tandem disk + sweep tillage as needed
B	Sweep plow twice	Tandem disk and harrow twice	Atrazine + propachlor + cultivation 1.7 + 3.3 kg/ha	Tandem disk + sweep tillage as needed
C	Atrazine + paraquat 1.7 + 0.3 kg/ha	Shallow seedbed preparation	Propachlor + atrazine 2.7 + 1.1 kg/ha	Herbicides[b] + tillage
D	Atrazine + paraquat 1.7 + 0.3 kg/ha	Paraquat 0.3 to 0.9 kg/ha	Paraquat + propachlor + atrazine 0.3 + 2.7 + 1.1 kg/ha	Herbicides[b] as needed
E	Paraquat twice 0.3 to 0.6 kg/ha	Paraquat twice 0.3 to 0.9 kg/ha	Paraquat + propachlor + atrazine 0.3 + 2.7 + 1.1 kg/ha	Herbicides[b] as needed

[a]A = tillage, B = tillage + herbicides, C = ecofallow-atrazine + seedbed preparation for sorghum, D = ecofallow-atrazine, and E = ecofallow-no atrazine.

[b]Paraquat + cyanazine at 0.3 + 2.2 kg/ha, or paraquat + cyanazine + atrazine at 0.3 + 1.8 + 0.6 kg/ha with paraquat at 0.3 to 1.7 kg/ha, or glyphosate at 0.6 or 0.9 kg/ha to kill escaped weeds.

millet (*Panicum miliaceum* L.) in another, and the third strip was fallowed and planted to winter wheat in September. The millet was planted to provide stubble for the following year's sorghum crop. In 1963, sorghum was planted but not harvested. Data were collected beginning in 1964 after each crop was in proper sequence and were taken over a 15-yr period.

Five treatments were replicated five times in a latin square design within each strip (Table 1). Plot size was 5 by 15 m. The treatments remained on the same plots during the duration of the experiment. The two tillage treatments (A and B) represented the two standard practices for the area in 1962. Treatment B represented the most advanced herbicide technology in conventional tillage. A tractor-mounted row cultivator was used to cultivate the sorghum 3 and 5 weeks after planting in treatments A and B. The ecofallow-atrazine plus seedbed preparation plots (treatment C) received shallow tillage before planting sorghum with a tandem disk plus harrow during 1964 to 1967 or a powered tiller with curved rotating blades operating at a 5- to 8-cm depth after 1967. Herbicides and tillage were used to control weed escapes during the fallow period before wheat seeding. The ecofallow-atrazine (treatment D) and ecofallow-no atrazine (treatment E) plots were never tilled during the duration of the experiment.

All treatments were applied as timely as possible to minimize weed growth. Number of weeds was recorded and harvested in a 1-m^2 quadrat per plot selected at random each time weeds were harvested before each tillage or spraying operation. The tillage tools used for fallowing were tandem disk, a sweep plow with 152- or 76-cm sweeps, and a rodweeder with semichisels. Plant residue measurements were made by collecting the plant material in a 1-m^2 quadrat selected at random in each plot after wheat and sorghum harvest and before planting winter wheat.

'RS610' and 'RS626' sorghum hybrids were planted with several different planters during the experiment. In 1964, a rigid-till planter[4] with 38-cm sweeps was used. A flexible planter[4] with 18-cm sweeps was used until 1972 when it was replaced by a flexible-slot planter[4]. Row spacing for sorghum was 102 cm in 1963 and 1964 and 76 cm thereafter. Seed was treated in the planter box with lindane (gamma isomer of benzene hexachloride) for wireworm (*Melanotus* spp.) control. Sorghum was planted about 3 cm deep at about 129 000 seeds/ha.

Three winter wheat cultivars were used: 'Scout' was planted in 1962 to 1964, 'Lancer' in 1965 to 1972, and 'Centurk' in 1973 to 1979. Wheat cultivar selection was based on improved cultivars being used at the time. Wheat was seeded at 67 kg/ha with a hoe drill equipped with 10-cm openers spaced 30 cm apart for the first 7 yr and with a hoe drill equipped with spear point openers spaced 36 cm apart for the following 10 yr. Seedbed preparation on the tilled plots (treatments A, B, and C) involved disking, sweep plowing, and rod weeding to minimize weed growth.

Ammonium nitrate was broadcast for plots to be planted to sorghum during March to June 1 depending on field conditions. The plots received 45 kg N/ha during 1962 to 1965, 67 kg N/ha during 1966 to 1969, and 90 kg N/ha during 1970 to 1979. Phosphorus was applied broadcast to sorghum ground at 22 kg P/ha from 1970 to 1979. The phosphorus source used was triple super phosphate (0-46-0). The winter wheat was fertilized with 22 kg N/ha during 1963 to 1965, 45 kg N/ha during 1966 to 1969, and 67 kg N/ha from 1970 to the end of experiment with ammonium nitrate (34-0-0). Broadcast applications were made during early April when the winter wheat was in the tillering stage. Changes in fertilizer practices reflect improvement in yield levels and overall management practices.

Herbicides were applied with a tractor-mounted sprayer equipped with 110° flat-fan nozzles. The carrier was water at a volume of 187 L/ha and dispersed with 208 kPa. When improved herbicides became available they replaced less

[4] Fleischer Mfg., Box 848, Columbus, NE 68601.

effective herbicidal treatments during the experiment. Also herbicide rates were adjusted to reflect changing production practices, weed population, and weed species. From 1962 to 1965, treatments C and D received atrazine at 2.2 or 3.3 kg ai/ha plus amitrole (1*H*-1,2,4-triazol-3-amine) at 0.6 to 2.2 kg/ha or butoxyethyl ester of 2,4-D [(2,4-dichlorophenoxy)acetic acid] at 0.6 to 1.1 kg ae/ha after wheat harvest. From 1965 to the end of the experiment, atrazine plus paraquat (1,1′-dimethyl-4,4′-bipyridinium ion) at 1.8 + 0.3 kg/ha was used on C and D. For weed control on treatment E, amitrole and 2,4-D were used until 1965. Thereafter, paraquat at 0.3 to 1.8 kg/ha replaced the amitrole.

Herbicides used to control weeds before or after sorghum emergence included amitrole, which was replaced by paraquat in 1965 on treatments C, D, and E before sorghum emergence. On treatment B in 1965, atrazine at 2.2 kg/ha was changed from preemergence to a preplant soil-incorporated application. Starting in 1970, atrazine at 1.7 kg/ha was incorporated followed by propachlor [2-chloro-*N*-(1-methylethyl)-*N*-phenylacetamide] at 3.3 kg/ha applied preemergence. Treatments C, D, and E were sprayed preemergence with atrazine at 2.2 kg/ha in 1965; in 1966 and 1967 atrazine at 2.2 kg/ha + 9 L/ha crop oil was applied postemergence; norea [*N*,*N*-dimethyl-*N*′-(octahydro-4,7-methano-1*H*-inden-5-yl) urea 3α, 4α, 5α, 7α, 7aα-isomer] plus atrazine at 1 + 0.5 kg/ha in 1968 and propachlor plus atrazine at 3.3 + 0.9 kg/ha in 1969 to 1970; and propachlor plus atrazine at 2.7 + 1.1 kg/ha for the remainder of the experiment. A postemergence application of 2,4-D ester at 0.3 kg/ha was used to control broadleaf weeds in sorghum in the tillage treatment (treatment A) about 4 weeks after planting.

During the fallow period after sorghum, amitrole, 2,4-D, and paraquat were used from 1962 to 1974. After 1974, paraquat plus cyanazine {2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino]-2-methylpropanenitrile} at 0.3 + 2.2 kg/ha, respectively, or paraquat plus cyanazine plus atrazine at 0.3 + 1.8 + 0.6 kg/ha was used to provide initial weed control in the sorghum stubble. Escaped weeds were controlled with paraquat at 0.3 to 1.8 kg/ha or glyphosate [*N*-(phosphonomethyl)glycine] at 0.6 or 0.9 kg ae/ha. Volunteer sorghum was difficult to kill with paraquat. From 1963 to 1974 escaped sorghum was removed by hand to prevent large soil water losses. After 1974, glyphosate was used to control volunteer sorghum. Treatment C received herbicides until about July 1, then sweep tillage was used to control weeds until wheat planting. Winter wheat was sprayed only in 1 yr (1964), with 2,4-D ester at 0.3 kg/ha to control kochia.

The principle weeds infesting the experimental area were barnyardgrass, green foxtail, stinkgrass [*Eragrostis cilianensis* (All.) Lutati # ERACI], witchgrass (*Panicum capillare* L. # PANCA), redroot pigweed, kochia, and Russian thistle (*Salsola collina* Pall.). Downy brome (*Bromus tectorum* L. # BROTE) was seeded over the area at the initiation of the experiment.

The annual precipitation during the experiment averaged 488 mm compared to 491 mm average for 80 yr. Average precipitation during April, May, June, July, August, and September was 51, 86, 93, 74, 45, and 49 mm, respectively. The long-term average was 55, 84, 86, 69, 54, and 43 mm, respectively. The average daily pan evaporation was 6, 7, 8, 9, 8, and 6 mm, respectively, for the months of April through September.

Winter wheat and grain sorghum were harvested with a plot combine. Wheat was harvested during mid-July from a 2.4- by 12-m area. Sorghum was harvested from three rows 12 m in length in October. Yields are expressed as oven-dry grain. Soil water measurements were taken in each plot in three replications at 30-cm-depth intervals with a neutron scatter probe to a depth of 180 cm during 1964 through 1974. Soil water readings were taken before planting and after harvest of wheat and sorghum.

In 1962, 1966, 1969, 1970, and 1986 composite soil samples from the 0- to 15-cm depth were taken from the whole area to assess the general fertility level. In September of 1980 soil samples were taken from 2.5-cm increments to a depth of 15 cm in all treatments in the three phases of the rotation. These were analyzed for pH; NH_4OAC-; exchangeable K, Ca, and Mg; organic matter (O.M.); NO_3-N, Bray 1-P; and 0.1*N* HCl-Zn (6).

Analyses of variance were computed on all data (SAS Institute). The pH data were converted to (H^+) to avoid the inaccurate averaging of log values for pH over replicates and treatments. The average [H^+] values were then converted to pH after averaging. Differences among treatments were compared using Duncan's multiple range tests at the 5% level of probability or linear contrasts.

RESULTS AND DISCUSSION

Planting winter wheat into the untilled plots (treatments D and E) was not a serious problem in most years. The biggest potential problem was risk of the soil becoming too hard for drill openers to penetrate in years of low rainfall in August and September before wheat planting. However, when sorghum row spacing was reduced from 102 to 76 cm in 1965, higher residue levels were maintained which minimized this problem.

The rigid-till planter used in 1964 covered too much wheat straw during the planting of sorghum and was not used again. A flexible planter with 18-cm sweeps was used for 7 yr with few problems. The flexible-slot planter performed well during the duration of the experiment.

Weed species. There were 16 weed species identified during the experiment. Barnyardgrass, witchgrass, green foxtail, stinkgrass, kochia, Russian thistle, and redroot pigweed were the resident species. Downy brome was introduced to all plots at the beginning of the experiment and was not a problem in the winter wheat because of the crop rotation. Common purslane (*Portulaca oleracea* L. # POROL), common sunflower (*Helianthus annuus* L. # HELAN), prostrate pigweed (*Amaranthus blitoides* S. Wats. # AMABL), slimleaf lambsquarters (*Chenopodium leptophyllum* Nutt. # CHELE), smooth groundcherry (*Physalis subglabrata* Mack. Bush. # PHYSU), and prostrate knotweed (*Polygonum aviculare* L. # POLAV) were identified during the experiment but

Table 2. Weed yields during selected intervals within the 3-yr rotation after sorghum harvest (15-yr averages).

Treatment[a]	Wheat stubble				Sorghum stubble			
	At harvest	July 20–Nov. 1	April 1–May 15	Total	At harvest	April 1–June 30	July 1–Sept. 15	Total
	(kg/ha)[bc]							
A	230 a	300 a	440 a	970 a	630 a	530 a	320 a	850 a
B	160 b	310 a	390 a	860 a	110 c	330 b	220 bc	550 b
C	200 ab	140 b	190 b	530 b	110 c	170 c	130 c	300 c
D	200 ab	110 b	60 c	370 b	90 c	130 c	80 c	210 c
E	170 b	140 b	220 b	530 b	220 b	150 c	50 c	200 c

[a]A = tillage, B = tillage + herbicides, C = ecofallow-atrazine + seedbed preparation for sorghum, D = ecofallow-atrazine, and E = ecofallow-no atrazine.

[b]Numbers followed by the same letter within columns are not significantly different at the 5% level according to Duncan's multiple range test.

[c]Weed yields represent one or more clippings of weed growth (oven-dry) during period.

populations of these weeds did not increase. Puncturevine (*Tribulus terrestris* L. # TRITE) and field sandbur were introduced through vehicle traffic. Although these two weeds did not cause problems in this experiment, they represent potential problems in an ecofarming system. Field sandbur became a problem in this rotation in Kansas (20), and farmers have reported that field sandbur and puncturevine are a problem in sandy soils under ecofallow in Nebraska.

Potential interference between summer annual broadleaf weeds and winter wheat occurred once in 15 yr. In April 1964, 2,4-D ester at 0.3 kg/ha was applied to control kochia in Scout wheat.

Weed populations and biomass from wheat harvest to sorghum planting. The effects of the five management treatments (Table 1) over the duration of the experiment on weeds were measured by weed yields and populations of various species. Weed yields taken before spraying herbicides or sweep plowing after winter wheat harvest were less than 250 kg/ha (Table 2). Populations of weed species were about the same on all treatments except that more grasses were found in tillage treatment A (Figure 1). Weeds growing in the wheat did not extend above the canopy of winter wheat and probably had little influence on grain yields.

Volunteer wheat was the principal weed present during the period from July 20 to November 1 (Figure 2). Plots sprayed with herbicides (treatments C, D, and E) had less than half the weed yield compared to those that were tilled (Table 2). The C and D treatments had received atrazine plus paraquat at 1.7 + 0.3 kg/ha after harvest. Volunteer wheat and downy brome (Figure 2) were killed with atrazine or an additional application of paraquat or glyphosate. Volunteer wheat and downy brome were difficult to control with a preemergence application of atrazine especially when seedlings emerged after application. At least three reasons are possible: excess seed, insufficient rain, and dissipation of atrazine. If volunteer wheat seed populations were high, due to grain loss through the combine or heads falling to the ground during harvest, control was worse. Poor volunteer wheat control has been reported when rainfall did not move atrazine into the soil before the wheat germinated (37). Also insufficient control of downy brome has been reported with atrazine at 1.7 kg/ha when applied in August (9). Atrazine applied in July is subject to loss by photodecomposition (16), volatility (16), and tie-up on the stubble (12).

The weed yields during the April 1 to May 15 period (before planting sorghum) were highest on the two tillage treatments. These plots received two tillage operations during this period and were heavily infested with volunteer wheat, kochia, and downy brome (Figure 3). Including a spring-planted crop (sorghum) in the rotation is a recommended control measure for downy brome (34). However, downy brome-infested wheat fields or pasture occurred on all sides of the experimental area and acted as a source for reinfestation. In plots sprayed with atrazine after wheat harvest (treatments C and D) downy brome and volunteer wheat were replaced by barnyardgrass and green foxtail as the major weed species. The amount of atrazine (1.7 kg/ha) applied 9 to 10 months before summer annual grass germi-

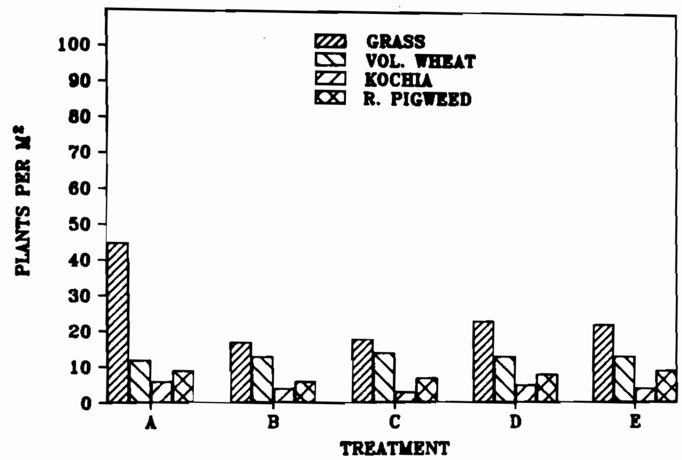

Figure 1. Population of weed species after wheat harvest as affected by treatments (see Table 1) when averaged over years.

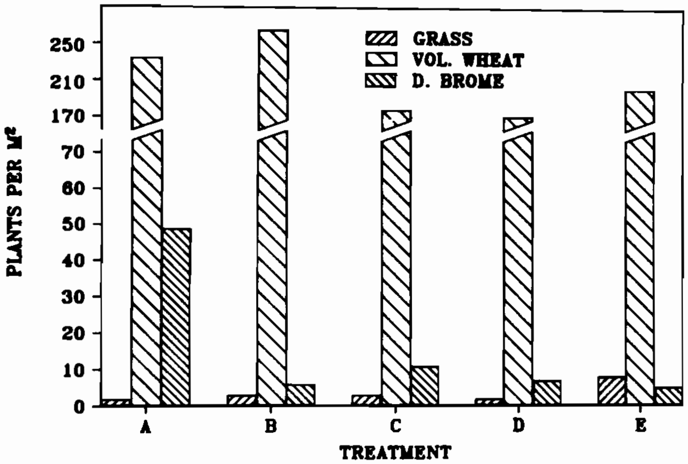

Figure 2. Total populations of weed species following wheat harvest until November 1 as affected by treatments (see Table 1) when averaged over years.

nation was not sufficient to prevent growth. Treatment E, which received only contact herbicides after wheat harvest, contained more kochia and winter annual and summer annual grass weeds than treatments C and D (Figure 3) but not in comparison to treatments A and B.

The total weed yields during the 10-month ecofallow period (wheat harvest to sorghum planting) were greatest on the two tillage treatments (Table 2). Total weed yields, composed largely of volunteer wheat, were similar among the three ecofallow treatments.

Weed populations 4 weeks after sorghum planting. Kochia, downy brome, volunteer wheat, and Russian thistle were controlled by tillage during seedbed preparation or with herbicides (Figure 4). Redroot pigweed, kochia, and Russian thistle were only present in treatment A. They were controlled with an application of 2,4-D ester at 0.3 kg/ha and cultivation.

Summer annual grasses were the major problem in all treatments. The propachlor plus atrazine at 2.7 + 1.1 kg/ha controlled 89, 97, 96, and 95% in treatments B, C, D, and E, respectively. The composition of the grasses for the last 3 yr were as follows: barnyardgrass 82%, green foxtail 13%, witchgrass 3%, and stinkgrass 2%. Most of the weeds on those plots treated with herbicides died and the remaining weeds did not compete with the sorghum except on treatment E plots (Table 3).

Weeds were effectively controlled in the sorghum by treatments B, C, D, and E as indicated by weed yields at sorghum harvest (Table 2). We observed a distinct advantage of using propachlor plus atrazine (treatment B) vs. 2,4-D plus cultivation (treatment A) since the latter did not control summer annual grasses in the row. Treatment E plots had more weeds (principally barnyardgrass) than treatment B, C, and D plots. Apparently, paraquat was not as effective in preventing barnyardgrass from producing seed after wheat harvest as were sweep plowing (treatment B), paraquat plus atrazine and seedbed tillage (treatment C), and paraquat plus atrazine (treatment D).

Population increase (data not shown) of barnyardgrass in treatments A and E was the only indication of a weed species increasing. Apparently, sufficient control of barnyardgrass prevented large seed accumulation in treatments B, C, and D. This research further substantiates the principle that weeds need to be controlled throughout a specific crop rotation rather than one portion of that rotation (2). Triplett and Worsham (30) stated that, "Management systems that reduce the weed seed population make weed control programs more effective". Even though weed yields were not great in sorghum and winter wheat, sufficient weeds were present to produce seed to infest succeeding crops. Additional pressure could be placed on weeds by making the winter wheat more competitive (31) or by using herbicides

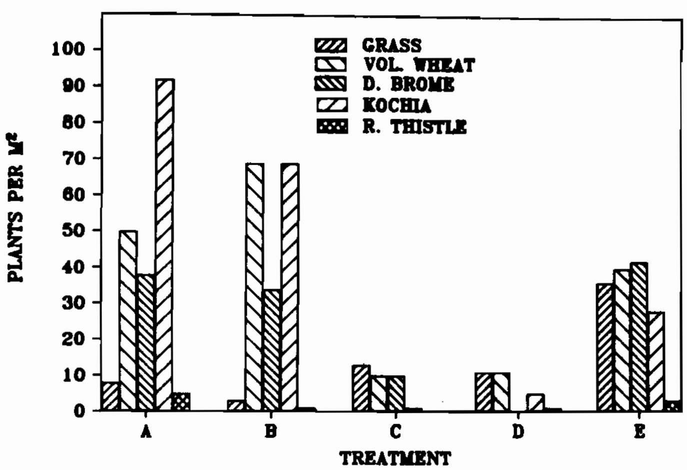

Figure 3. Total population of weed species between April 1 to sorghum planting as affected by treatments (see Table 1) when averaged over years.

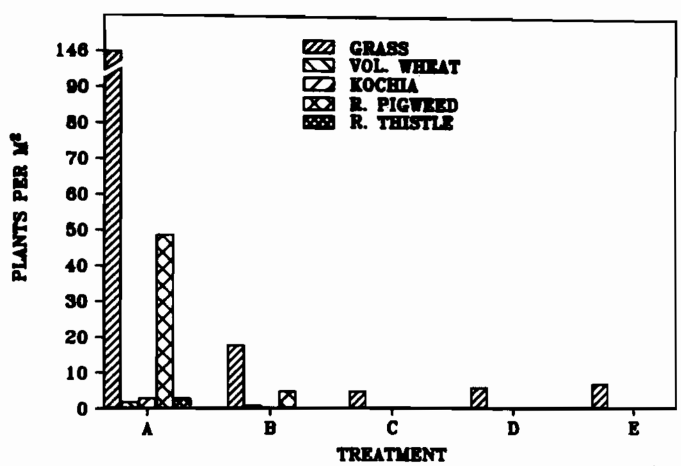

Figure 4. Population of weed species 4 weeks after sorghum planting as affected by treatments (see Table 1) when averaged over years.

Table 3. Plant residue after winter wheat and sorghum harvest and before seeding winter wheat, soil water gains, and winter wheat and grain sorghum yields as affected by selected treatments averaged over 15 yr.

Treatment[a]	Plant residue: After harvest, Wheat	Plant residue: After harvest, Sorghum	Plant residue: Prior to planting wheat	Soil water gain to 180 cm[c]: Sorghum harvest to wheat seeding	Soil water gain to 180 cm[c]: Wheat harvest to sorghum planting	Oven-dry grain yield: Wheat	Oven-dry grain yield: Sorghum	Seed weight[c]: Wheat	Seed weight[c]: Sorghum	Sorghum heads[c]
	(kg/ha)[b]			(cm)		(kg/ha)		(g/1000 seeds)		(no./m²)
A	3290 c	3330 c	520 c	15.4 b	11.1 c	2340 c	2200 d	24.4 c	18.3 b	9.8 b
B	3510 b	3670 b	700 c	15.6 b	11.0 c	2420 c	2880 c	24.5 bc	18.7 ab	9.8 b
C	3540 b	3900 b	1120 b	17.0 b	14.3 b	2590 b	3200 b	25.2 ab	18.1 b	11.4 a
D	3490 b	4150 a	2070 a	19.3 a	17.9 a	2690 ab	3460 a	25.4 a	19.2 a	11.0 a
E	3770 a	4350 a	2110 a	20.3 a	16.4 a	2720 a	3200 b	24.8 abc	19.2 a	11.0 a

[a]A = tillage, B = tillage + herbicides, C = ecofallow-atrazine + seedbed preparation for sorghum, D = ecofallow-atrazine, and E = ecofallow-no atrazine.

[b]Numbers followed by the same letter within columns are not significantly different at the 5% level according to Duncan's multiple range test.

[c]Data collected during 1965–1974.

in the growing wheat (11, 15). One weed problem that needs to be addressed is volunteer grain. Selection of cultivars that shatter less combined with an increase in harvesting efficiency represent a practical approach to this problem.

Weed populations and biomass between sorghum harvest and winter wheat planting. Weed yields taken from April 1 until September 15 indicate the four treatments that received propachlor plus atrazine at 2.7 + 1.1 kg/ha following planting of sorghum had lower weed yields during the 5.5-month period (Table 2). No-till plots had lower weed yields than treatment B during the April 1 to June 30 period and these weeds were mostly summer annual grasses. Kochia was present on all plots but its density was less on the ecofallow treatments that received atrazine after wheat harvest (Figure 5). Redroot pigweed populations were higher on the two tillage treatments, even though the same amount of atrazine was present on treatments B and E. Apparently redroot pigweed germination is favored by disturbed soils as observed with other weed seed (24). Volunteer sorghum present on the no-till plots was a serious problem during the fallow period and glyphosate was the only herbicide that provided satisfactory control. Weed pressure was less from July 1 to wheat planting as indicated by weed yields (Table 2) and weed populations (Figure 6). However, if not controlled this amount of weed growth would deplete the soil water required for winter wheat germination.

Winter wheat and sorghum yields. Winter wheat yields were greatest on the plots that received no or minimal tillage (treatments C, D, and E) during the experiment because more water was stored during the fallow period between

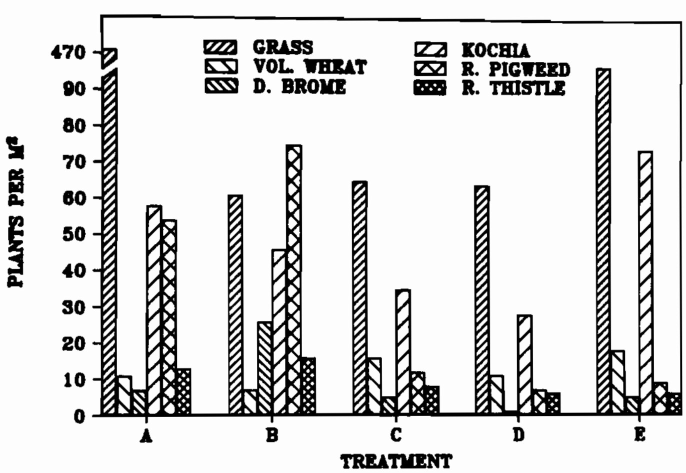

Figure 5. Total population of weed species during the April to July 1 fallow period after sorghum harvest as affected by treatments (see Table 1) when averaged over years.

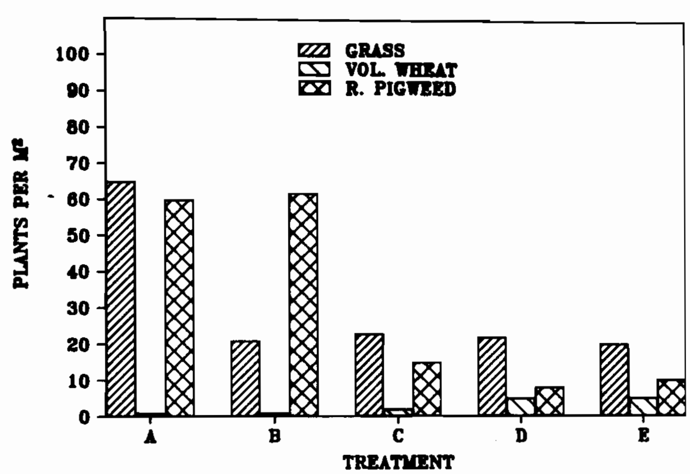

Figure 6. Total populations of weed species during the fallow period from July 1 until September 15 before seeding winter wheat as affected by treatments (see Table 1) when averaged over years.

sorghum harvest and wheat planting (Table 3). Plots that were tilled (treatments A and B) had 71% less wheat plus sorghum residue before planting winter wheat (Table 3) than did plots that were not tilled (treatments D and E). Water storage was greater in untilled plots because infiltration was greater and evaporation was less since more residue and fewer weeds were present than in tilled plots (Tables 2 and 3). Hence, these two factors contributed to lower wheat yields on the tilled plots (treatments A and B).

Sorghum yields were greater on the three ecofallow treatments (Table 3), which had more soil water stored than plots receiving tillage (Table 3). Also there were fewer sorghum heads at harvest time on the tillage plots because of less optimum moisture conditions during tiller initiation (Table 3). Treatment D yielded more grain than treatment B every year except 1974 and 1977. An early frost on September 14, 1974, stopped seed development, and yields on treatments D and B were 3180 and 3820 kg/ha, respectively. In 1977, a planting delay (June 12) plus a cool August (21 C, below normal) delayed flowering on plots planted into residue (treatment D), and sorghum did not mature before frost on October 12. Residue on treatment D kept soil cooler and slowed development of plants. Yields were 3920 and 4650 kg/ha for treatments D and B, respectively. Even though treatments C and D received the same herbicides, treatment C had less yield which was due to the soil water loss associated with seedbed preparation (Table 3). During the initial years treatment C was tilled without thought of the importance of the wheat stubble for water conservation. In later years the plots were tilled shallow and less difference in sorghum yield occurred between treatments C and D. Treatment E sorghum grain yield was less than treatment D because summer annual grass control was not adequate in the sorghum crop. The additional atrazine applied after wheat harvest in treatment D improved grass control in the sorghum by reducing seed population (37) and more atrazine was available for weed control. Weed yields at sorghum harvest were not great (Table 2). All treatments that received atrazine after sorghum planting had lower weed yields than treatment A.

Soil chemical properties. In 1962 when this experiment was initiated, soil samples from the 0- to 15-cm depth showed a pH of 7.2, organic matter content of 1.6%, and a surface texture of a silt loam. In 1966, a composite soil sample from the whole plot area from the 0- to 15-cm depth had a pH of 6.7, Bray 1-P of 21 ppm, 625 ppm K, and an organic matter content of 1.8%. The soil had a cation exchange capacity of 15.2 milliequivalents per 100 grams and the following base saturation percentages: Ca, 67%; Mg, 19%; and K, 12%.

pH. Data for treatments B and D are presented in Table 4 for the three different crop sequence strips. Treatment B received the most tillage during the experiment and treatment D received no tillage during 18 yr. One of the first and most noticeable changes under no-till is the change in soil pH. This has especially been noted in more humid climates (1). In the Great Plains many soils are neutral to alkaline in the surface soil. However, after 18 yr of shallow tillage (treatment B) and no soil mixing (treatment D), pH had declined to levels between 5.3 to 5.8 in the surface 15 cm of soil. An acidic soil surface (pH less than 5.5) results in rapid deactivation of triazine herbicides that are commonly used in this crop rotation (20). The increasing use of N fertilizer over time (10) and the lack of soil mixing had a definite influence on leaching of exchangeable bases under the no-tillage system even in this semiarid climate.

Table 4. Effect of tillage practices for 18 yr on soil characteristics. Treatment B is tillage and treatment D is no-tillage. (See Table 1.)

Soil depth	Fallow		Wheat stubble		Sorghum		Fallow		Wheat stubble		Sorghum	
	B	D	B	D	B	D	B	D	B	D	B	D
(cm)	(pH)						(% O.M.)					
0–2.5	5.5	4.8*	5.2	4.9*	5.5	5.1*	2.1	2.2	2.2	2.4	2.0	2.4
2.6–5.0	5.7	5.2*	5.2	5.2	5.5	5.4	1.9	1.8	1.9	1.7	1.9	1.7*
5.1–7.5	5.8	5.7	5.4	5.9*	5.7	5.9*	1.7	1.6	1.7	1.5	1.7	1.6
7.6–10.0	6.0	6.1	5.5	5.9*	5.7	6.1*	1.6	1.6	1.6	1.7	1.7	1.6
10.1–12.5	6.0	6.1	6.0	6.2	5.7	6.0*	1.5	1.7	1.5	1.6	1.8	1.6
12.6–15.0	6.2	6.2	6.3	6.4	5.8	6.0	1.3	1.4	1.4	1.4	1.6	1.7
Avg.	5.8	5.3*	5.5	5.4	5.6	5.6	1.7	1.7	1.7	1.7	1.8	1.8
	(ppm 0.1N HCl Zn)											
0–2.5	2.5	3.5*	2.2	2.4	2.1	2.4*						
2.6–5.0	2.2	3.5*	2.1	2.1	1.9	1.8						
5.1–7.5	2.1	2.4	2.1	1.7*	1.6	1.9						
7.6–10.0	1.9	2.1	1.9	1.7	1.7	1.5						
10.1–12.5	1.7	1.8	1.5	1.4	1.5	1.8						
12.6–15.0	1.8	1.7	1.4	1.5	1.6	1.9						
Avg.	2.0	2.5	1.9	1.8	1.7	1.9						

*Significant differences between treatments at the 5% level of significance according to single degree of freedom linear contrasts by strip and depth.

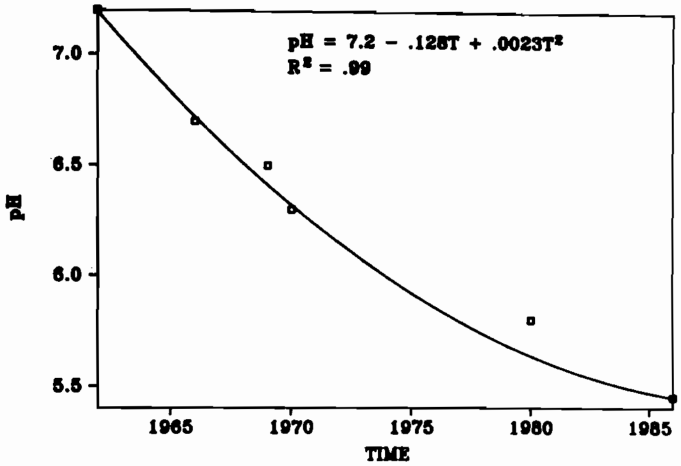

Figure 7. Change in pH for the 0- to 15-cm depth from the tillage plots after 24 yr.

Surface pH of the top 2.5 cm for the three strips showed an average pH of 5.0. There was a significant decrease in pH between the tilled compared to the no-till plots at this depth in all instances (Table 4). The leaching that occurred in the surface 5 cm of the untilled treatment showed evidence of exchangeable base movement (primarily calcium) to the 5.1- to 10.0-cm depth. Significant differences between pH's for the 5.1- to 7.6- and 7.6- to 10-cm depths were shown under the wheat stubble and for the 5.1- to 12.5-cm depth in the sorghum strips (Table 4).

Composite soil samples taken during 1962, 1966, 1969, 1970, and 1986 to assess the general soil fertility level showed that soil pH for 0 to 15 cm declined steadily over time (Figure 7). The surface pH declines were not sufficient to cause reduced performance of the triazine herbicides and had no effect on grain yield. The no-till plots overall showed higher grain yields than the tilled plots (Table 3). The data do show the importance of incremental soil sampling to monitor soil pH changes. Ghadari et al. (12) reported that soil pH increased from a slightly acid level in the upper 15 cm to over 7 in the 24- to 30-cm depth. Due to the high cost of lime transportation, liming these soils to neutralize the top 15 cm is not economical for the crop yield levels obtained in western Nebraska. However, research is needed to determine if low application rates of finely ground limestone will neutralize the acidity in the top 3 or 4 cm of soil enough to improve the weed control activity of the triazine herbicides. Surface liming has proven successful in no-till in more humid climates (1, 17).

O.M. Organic matter content showed very little change during the 18 yr and was not greatly different between nontilled and tilled plots at the various depth increments (Table 4).

HCl ZN. The 0.1N HCl extractable zinc was higher in the 0- to 2.5-cm depth for the nontilled plots compared to the till plots for the fallow and sorghum strips (Table 4). The greater acidification of the nontilled treatments is the primary cause of the change (18). Zinc levels for the 0- to 15-cm depth were similar to those found in the 1966 sampling. During the course of the experiment no zinc fertilizer was added to these plots.

NO_3-N. Nitrate (NO_3-N) levels in the cropped soils in 1980 were not significantly different between the nontilled and

Table 5. Effect of tillage practices for 18 yr on soil characteristics. Treatment B is tillage and treatment D is no-tillage. (See Table 1.)

	Fallow		Wheat stubble		Sorghum		Fallow		Wheat stubble		Sorghum	
Soil depth	B	D	B	D	B	D	B	D	B	D	B	D
(cm)	(ppm NO_3-N)						(ppm Bray 1-P)					
0–2.5	20	116*	15	20	8	12	114	191*	129	143	63	73
2.6–5.0	21	28	11	8	10	9	74	129*	120	84	51	44
5.1–7.5	20	19	11	5*	15	4	42	54	64	29*	27	19
7.6–10.0	21	20	11	5	16	6*	26	26	51	28	24	12*
10.1–12.5	20	19	13	7*	15	8	25	26	22	17	34	19
12.6–15.0	20	25	12	7*	13	8	21	16	15	16	30	20
Avg.	20	38*	12	8*	13	8	50	74*	67	53	38	31
	(meq/100 g Ca)						(ppm K)					
0–2.5	6.0	5.1*	4.9	4.0*	5.3	4.2*	766	727	658	656	745	616*
2.5–5.0	6.5	5.8	5.0	5.1	5.4	5.2	641	612	732	609*	632	564*
5.1–7.5	7.5	6.8*	5.7	6.9*	6.3	6.4	577	591	640	537*	593	534
7.6–10.0	8.5	7.8	6.3	7.4*	7.1	7.6*	528	534	645	572	572	522
10.1–12.5	8.6	8.3	7.9	8.7	7.0	7.4	496	520	605	475*	587	514*
12.6–15.0	8.7	9.0	8.7	8.8	7.0	7.7	424	435	483	510	532	463
Avg.	7.6	7.1	6.4	6.8	6.4	6.4	572	570	627	560*	610	535

*Significant differences between treatments at the 5% level of significance according to single degree of freedom linear contrasts by strip and depth.

tilled plots (Table 5). However, in the fallowed strips more NO_3-N was found in the top 2.5-cm layer in the nontilled plots compared to the tilled plots (Table 5). The NO_3-N distribution under the tilled plots was very uniform over the 15-cm sampling depth.

P. With the limited amount of tillage, even in the tilled plots, stratification of P is expected (29). Bray 1-P levels were increased dramatically in this soil compared to the composite sampling in 1966. Significant differences in P concentrations in the top 5 cm were shown for the fallowed strip but not for the crop strips and cannot be explained (Table 5).

Exchangeable cations. Exchangeable K levels in this soil were initially very high and showed a slight decrease over the 18 yr. In 1966, exchangeable Ca represented 67% of the exchangeable bases when pH was 6.6. In 1980, Ca represented 49% of the exchangeable bases from the 0- to 15-cm depth when pH was 5.6. This change in Ca is primarily attributed to leaching. Magnesium and K saturation percentages were 21 and 11% in 1980 compared to 19 and 12% in 1966 when averaged over all treatments.

The two main differences between minimum-tillage and conventional-tillage systems in the winter wheat-sorghum-fallow rotation are the additional residues on the soil surface and the reduced soil mixing. These factors may greatly change the soil environment of a no-tillage system compared to a tillage system that destroys surface residue. Several references in the literature discuss changes in physical, chemical, and biological properties of the soil as influenced over time by conservation tillage (1, 5, 22, 28) compared to conventional tillage.

This experiment has shown that more water was stored and greater grain yields were obtained when herbicides were used in place of tillage alone. Nitrogen rates were increased to correspond with more soil water storage under the reduced tillage. Earlier application of N caused the N to move into the soil as the water was stored and thus was available during time of crop growth. Early planting and proper sorghum hybrid selection were important. The ground was cooler beneath the mulch and this delayed sorghum maturity. Atrazine persistence was not a problem. Rates did not exceed those suggested for sorghum (3). Although there were changes in the soil chemical properties, they were at a slower rate of change than found in more humid areas (1). In this research soil property changes did not reduce weed control or crop yield. Many obstacles were overcome since this experiment was initiated in 1962 and through proper decisions many potential problems were avoided. Management is the key to successful use of herbicides to replace tillage in the Central Great Plains.

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