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Abstract

Emerging challenges in continuous no-till (NT) systems require developing flexible management strategies that will minimize the impacts of herbicide resistant (HR) weeds and nutrient stratification on soil and crop productivity. This study evaluated the effectiveness of strategic tillage (ST) operations as an option to redistribute soil nutrients and acidity, control perennial grass and HR weeds, and improve crop yields following tillage of an otherwise long-term NT soil. Treatments were five crop rotations: 1) continuous winter wheat (WW); 2) wheat-fallow (WF); 3) wheat-sorghum-fallow (WSF); 4) continuous sorghum (SS); and 5) sorghum-fallow (SF) as main plots. Sub-plots were reduced tilled (RT), continuous NT, and ST of long-term NT. Grass and herbicide resistant weeds were reduced with tillage. Irrespective of crop rotation, soil water content at wheat planting was significantly less with RT treatments compared to NT or ST. Soil water content with NT was not different from that of ST under cropping systems with fallow (WF or WSF). Tillage (ST or RT) reduced soil water content at wheat planting in WW system. Winter wheat grain yields decreased with increasing cropping intensity, WF (26-48 bu/a) > WSF (22-33 bu/a) > WW (15-19 bu/a). Averaged across years and crop rotations, wheat yield with ST was 30 bu/a, which was greater than the NT (23 bu/a) or RT (28 bu/a) systems, mostly due to better weed control and increased nutrient availability. Sorghum grain yield over the 2 years with ST (63 bu/a) was not different from that of NT (61 bu/a), but were both greater than that of RT (54 bu/a). Increasing cropping intensity reduced sorghum grain yield, average grain yield with SF was 73 bu/a, similar to WSF (68 bu/a), but greater than SS (38 bu/a). Tillage had no effect on soil bulk density. However, increasing cropping intensity lowered the bulk density measured in the upper 0 to 2 in. of the soil. Tillage and crop rotation effects on soil organic matter (SOM), pH, and nutrient concentrations occurred only in the top 0- to 2-in. depth. The SOM, iron (Fe), and manganese (MN) concentrations were greater in soils under WW compared to WF or WSF. Soil pH and potassium (K) were least in soils under WW. The SOM concentration in the top 0 to 2 in. with NT was 3.34%, which was similar to that of soil under ST (3.02%) but both were greater than RT (2.65%). Nitrate-N concentration increased with ST but ammonium-N concentration was greatest in soils under NT. Our results suggest ST could provide a mitigation option for HR weeds in NT crop production with little impact on crop yields and soil chemical properties.

Keywords

dryland, herbicide-resistant weeds, no-tillage, strategic tillage

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Summary

Emerging challenges in continuous no-till (NT) systems require developing flexible management strategies that will minimize the impacts of herbicide resistant (HR) weeds and nutrient stratification on soil and crop productivity. This study evaluated the effectiveness of strategic tillage (ST) operations as an option to redistribute soil nutrients and acidity, control perennial grass and HR weeds, and improve crop yields following tillage of an otherwise long-term NT soil. Treatments were five crop rotations: 1) continuous winter wheat (WW); 2) wheat-fallow (WF); 3) wheat-sorghum-fallow (WSF); 4) continuous sorghum (SS); and 5) sorghum-fallow (SF) as main plots. Subplots were reduced tilled (RT), continuous NT, and ST of long-term NT. Grass and herbicide resistant weeds were reduced with tillage. Irrespective of crop rotation, soil water content at wheat planting was significantly less with RT treatments compared to NT or ST. Soil water content with NT was not different from that of ST under cropping systems with fallow (WF or WSF). Tillage (ST or RT) reduced soil water content at wheat planting in WW system. Winter wheat grain yields decreased with increasing cropping intensity, WF (26-48 bu/a) > WSF (22-33 bu/a) > WW (15-19 bu/a). Averaged across years and crop rotations, wheat yield with ST was 30 bu/a, which was greater than the NT (23 bu/a) or RT (28 bu/a) systems, mostly due to better weed control and increased nutrient availability. Sorghum grain yield over the 2 years with ST (63 bu/a) was not different from that of NT (61 bu/a), but were both greater than that of RT (54 bu/a). Increasing cropping intensity reduced sorghum grain yield, average grain yield with SF was 73 bu/a, similar to WSF (68 bu/a), but greater than SS (38 bu/a). Tillage had no effect on soil bulk density. However, increasing cropping intensity lowered the bulk density measured in the upper 0 to 2 in. of the soil. Tillage and crop rotation effects on soil organic matter (SOM), pH, and nutrient concentrations occurred only in the top 0- to 2-in. depth. The SOM, iron (Fe), and manganese (MN) concentrations were greater in soils under WW compared to WF or WSF. Soil pH and potassium (K) were least in soils under WW. The SOM concentration in the top 0 to 2 in. with NT was 3.34%, which was similar to that of soil under ST (3.02%) but both were greater than RT (2.65%). Nitrate-N concentration increased with ST but ammonium-N concentration was greatest in soils under NT. Our results suggest ST could provide a mitigation option for HR weeds in NT crop production with little impact on crop yields and soil chemical properties.

Introduction

No-tillage (NT) systems provide several benefits to dryland crop production in the semiarid central Great Plains (CGP). These include improvements to soil health, reduced wind erosion, fewer energy inputs, increased retention of soil moisture, and improved crop yields. Despite these benefits, maintaining continuous NT and the associated soil conservation benefits are at risk due to a lack of effective control of HR weeds, as well as issues of compaction and stratification of soil pH and nutrients. Stratification of soil nutrients and soil acidity could reduce nutrient availability and uptake by crops and increase the chances of nitrogen and phosphorus losses in surface runoff.

In addition, the lack of effective herbicides to control perennial grass weeds such as three-awn grass (*Aristida purpurea* Nutt.) and tumble windmill grass (*Chloris verticillata* Nutt.), and the advent of herbicide resistant weeds such as kochia (*Kochia scoparia* L.) and Palmer amaranth (*Amaranthus palmeri* S. Watson) pose challenges in NT crop production. With low grain prices and the high cost of controlling HR weeds, some producers are returning to tillage as a strategic management tool.

Strategic tillage (ST) with a sweep plow timed when soil erosion risk is low in an otherwise NT cropping system could help manage HR weed populations and reduce stratification of soil properties. After the one-time tillage operation, the field goes back to NT production. This ST approach could increase productivity and profitability of dryland cropping systems in the region. However, the soil health impacts of ST are unclear particularly in water-limited environments of the CGP where susceptibility to wind erosion can be high.

Few studies have investigated the effects of ST on soils that have been in continuous NT (> 40 years) in dryland conditions in the CGP. Our objectives were to determine the effects of ST in long-term NT systems on 1) soil water content at winter wheat planting; 2) winter wheat and grain sorghum yields; 3) effectiveness of ST to redistribute soil nutrients, reduce soil acidity, and control perennial grass and herbicide resistant weeds; and 4) determine soil quality following tillage of an otherwise long-term NT soil.

Procedures

This study was conducted using long-term tillage and crop rotation experiment plots established in 1976 at the Kansas State University Agricultural Research Center near Hays, KS. The experimental design was a randomized complete block with three replications in a split-plot treatment structure. Main plots were five crop rotations [continuous winter wheat (WW), wheat-fallow (WF), wheat-sorghum-fallow (WSF), continuous sorghum (SS), and sorghum-fallow (SF)] and two tillage treatments (RT and NT) as sub-plots. Every phase of each crop rotation and tillage system combination was present in each replication for each year of the study. The study was modified in the summer of 2016 to three tillage treatments [RT, continuous NT, and strategic tillage (ST) of NT] by splitting the long-term NT plots into two equal plots of 20-ft wide by 80-ft long. One half was left in continuous NT and the other half was tilled. The ST plots were tilled twice, first with a sweep plow to a 3-in. depth followed by a second tillage operation 3 days later to 6-in. depth, also with a sweep plow. All tillage operations in the wheat rotations were performed in July prior to winter wheat planting in October. For crop rotations involving sorghum, tillage operations were done in May before sorghum planting in June. Tillage in the RT treatments were accomplished with the same tillage implement to 6- to 8-in. depth. Two to three tillage operations were usually done in the RT plots over the fallow period.

Soil water content at winter wheat planting was determined gravimetrically to 4 ft, in 6-in. depth increments in 2016 and 2017. Two soil cores were taken from each plot and data averaged for a single soil water content measurement. Winter wheat and sorghum grain yields were determined by harvesting a 5 × 80 ft area from the center of each plot using a small plot combine. Soil samples were taken from 0 to 2, 2 to 6, 6 to 12 in. soil depths after tillage operations in 2017 only. These samples were analyzed for changes in bulk density, soil organic carbon (SOC), dry aggregate size distribution, and soil nutrients. The SOC was multiplied by a factor of 2 (because no calibrated conversion factor is available for this soil) and reported as SOM concentration.

Results

Weeds, Soil Water Content, and Bulk Density

In general, broadleaf and grass weeds were significantly less with RT and ST compared to the NT treatments (data not shown). Tillage × crop rotation interaction had a significant effect on soil water content measured at winter wheat planting. Regardless of crop rotation, soil water content with NT was similar to that of ST but were both greater than that measured with RT in crop rotation systems that had fallow (Figure 1). However, with WW system, tillage operation as either ST or RT reduced soil water at winter wheat planting compared to NT (Figure 1). Averaged across crop rotations, profile soil water content was 13.4 in. with NT or ST, and 12.6 in. with RT over the 2 years. In general, water content decreased with increasing cropping intensity, mostly due to increased crop water use. Averaged across the 2 years and tillage treatments, profile soil water content with WF was 13.7 inches, which was greater than WSF (13.2 inches) or WW (12.4 inches).

Soil bulk density measured within the top 12 in. of the soil was not different among tillage systems. Across crop rotations and sampling depth, bulk density averaged 1.16 g cm^{-3} with NT and 1.13 g cm^{-3} with ST or RT. However, crop rotation × depth interaction had a significant effect on bulk density. In general, bulk density within the top 0 to 6 inches decreased with increasing cropping intensity. The continuous wheat treatment had the lowest bulk density at 0 to 2 in., and 2 to 6 in. depth (Table 1), possibly due to greater contribution of plant residue input onto the soil surface. Bulk density was no different among the crop rotation systems beyond the 6-in. depth.

Soil pH and Nutrient Concentrations

Tillage system had no effect on soil pH, which averaged 5.5 for NT, 5.6 with ST, and 5.7 with RT at the upper 0 to 2 in. soil depth. Crop rotation × sampling depth interaction had a significant effect on soil pH. Regardless of crop rotation system, pH at the upper 0 to 2 in. was markedly lower than that measured in the subsurface. Averaged across tillage treatments, soil pH at the 0 to 2 in. depth was lowest in the WW production system (Table 1), possibly because of annual N fertilizer application and mineralization of SOM in this treatment. Soil pH measured below 2 in. depth was not different among crop rotations. The SOM concentration was significantly affected by crop rotation and tillage, but mostly within the top 0 to 2 in. Across tillage, SOM measured in the upper surface was 2.72% for WF, 2.74% for WSF, and 3.55% for WW. The differences were due to differences in crop residue addition that affected SOM accretion in the surface soil. When averaged across crop rotations, SOM concentration measured in the upper soil surface with ST was 3.02%, which was similar to 3.34% measured in soil under long-term continuous NT but were both greater than that with RT (Table 2). Tillage system had no effect on SOM concentration beyond the top 0 to 2 in. soil depth.

Tillage or crop rotation effects on soil nutrient concentrations were limited to the upper 0 to 2 in. of the soil. Soil K concentration in the upper surface decreased with WW compared to WF or WSF system. However, soil Fe and Mn concentrations increased with WW production system. Greater Mn and Fe concentration in soils under WW is possibly explained by the decrease in soil pH associated with the WW system that caused increased solubility of these cations. Soil P and Zn concentrations were not affected by tillage or crop rotation. Nitrate-N concentration measured in the upper soil surface increased under ST compared to NT or RT. This was possibly because of increased mineralization associated with tillage of the long-term NT soil. Expectedly, ammonium-N concentration was significantly greater in soils under NT (Table 2). However, soil K concentration increased in soils under RT compared to NT or ST system.

Winter Wheat and Grain Sorghum Yield

Winter wheat grain yield differed over the two years of the study. Crop rotation × year interaction had effect on winter wheat grain yield. Regardless of crop rotation, winter wheat grain yield in 2018 was significantly less than that achieved in 2017 (Figure 2). Averaged across tillage and crop rotation, wheat yield averaged 33.3 bu/a in 2017 and 20.7 bu/a in 2018. The differences were due to spring drought conditions in 2018. Winter wheat grain yields decreased with increasing cropping intensity, WF (26-48 bu/a) > WSF (22-33 bu/a) > WW (15-19 bu/a), which was expected due to decreased soil water availability for crop production when cropping intensity increased.

Similarly, tillage intensity had significant ($P = 0.0006$) effect on wheat grain yield. Across the 2 years and crop rotations, winter wheat yield with NT was 23 bu/a, which was less than the 30 bu/a obtained with ST or 28 bu/a with RT (Figure 3a). This is possibly due to improved grass weed control with tillage operations that reduced weed competition and improved plant establishment. It is also plausible that tillage operations of long-term NT increased nutrient availability, particularly N (Table 1) in the ST plots compared to continuous NT or RT treatments.

Average sorghum grain yield in 2017 was 47 bu/a, less than the 72 bu/a in 2018. Grain yields were significantly affected by crop rotation ($P = 0.0001$) and tillage ($P = 0.006$). Sorghum grain yield with ST was not different from that of NT, but were both greater than that of RT (Figure 3b). Similar to winter wheat, increasing cropping intensity reduced sorghum grain yield. Average grain yield of SF was 73 bu/a, similar to WSF (68 bu/a) but greater than SS (38.1 bu/a).

Table 1. Soil bulk density, organic matter, pH, potassium, iron, manganese, and copper concentration as affected by crop rotation and soil sampling depth

Crop rotation	0 to 2 inches	2 to 6 inches	6 to 12 inches	0 to 2 inches	2 to 6 inches	6 to 12 inches	0 to 2 inches	2 to 6 inches	6 to 12 inches	0 to 2 inches	2 to 6 inches	6 to 12 inches
	Bulk density, g cm^{-3}			Soil organic matter, %			Soil pH			Potassium, ppm		
Wheat-fallow	1.14 a	1.22 ab	1.21 a	2.72 b	2.27 a	1.79 a	5.7 a†	6.2 a	6.9 a	558 a	559 a	545 a
Wheat-sorghum-fallow	1.02 b	1.25 a	1.17 a	2.74 b	2.23 a	1.84 a	5.9 a	6.3 a	6.9 a	539 a	511 b	524 a
Continuous wheat	0.89 c	1.17 b	1.18 a	3.55 a	2.45 a	1.99 a	5.3 b	6.1 a	7.0 a	516 b	528 b	544 a
	Iron, ppm			Manganese, ppm			Phosphorus, ppm			Zinc, ppm		
Wheat-fallow	53 b	39 ab	22 a	27 b	21 b	12 a	41.2 a	19.8 a	8.2 a	0.64 a	0.43 a	0.25 a
Wheat-sorghum-fallow	47 b	35 b	22 a	26 b	21 b	12 a	37.7 a	13.8 a	6.0 a	0.76 a	0.37 a	0.27 a
Continuous wheat	77 a	46 a	22 a	43 a	25 b	12 a	44.1 a	16.5 a	4.6 a	0.75 a	0.39 a	0.39 a

†Means followed by same lower case letter(s) within a site-year are not significantly different. Upper case letter(s) denotes comparisons between site-years.

Table 2. Soil organic matter, nitrogen (N), and potassium concentrations as affected by tillage operation and soil sampling depth

Tillage system	0 to 2 inches	2 to 6 inches	6 to 12 inches	0 to 2 inches	2 to 6 inches	6 to 12 inches	0 to 2 inches	2 to 6 inches	6 to 12 inches	0 to 2 inches	2 to 6 inches	6 to 12 inches
	Soil organic matter, %			Nitrate-N, ppm			Ammonium-N, ppm			Potassium, ppm		
No-tillage	3.34 a	2.35 a	1.84 a	33.2 ab	16.3 a	7.6 a	13.2 a	3.3 a	2.6 a	516 b	538 a	543 a
Strategic tillage	3.02 a	2.40 a	1.97 a	37.4 a	16.9 a	9.9 a	8.3 b	3.2 a	2.6 a	515 b	517 a	535 a
Reduced tillage	2.65 b	2.21 a	1.81 a	30.7 b	15.8 a	11.2 a	4.4 c	2.7 a	2.5 a	582 a	543 a	535 a

†Means followed by same lower case letter(s) within a soil sampling depth are not significantly different. Upper case letter(s) denotes comparisons between site-years.

Figure 1. Soil water content at winter wheat planting as affected tillage in each crop rotation system. Data are averaged across 2 year and three replications (n = 6).

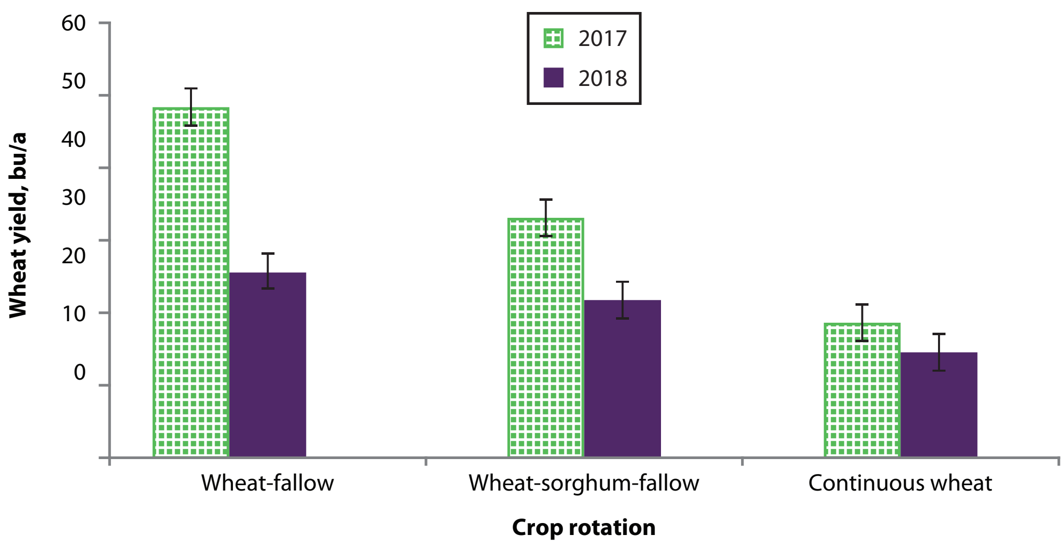

Figure 2. Winter wheat grain yield as affected by crop rotation system in 2017 and 2018 growing seasons at Hays, KS. Data are averaged across three tillage systems and three replications (n = 9).

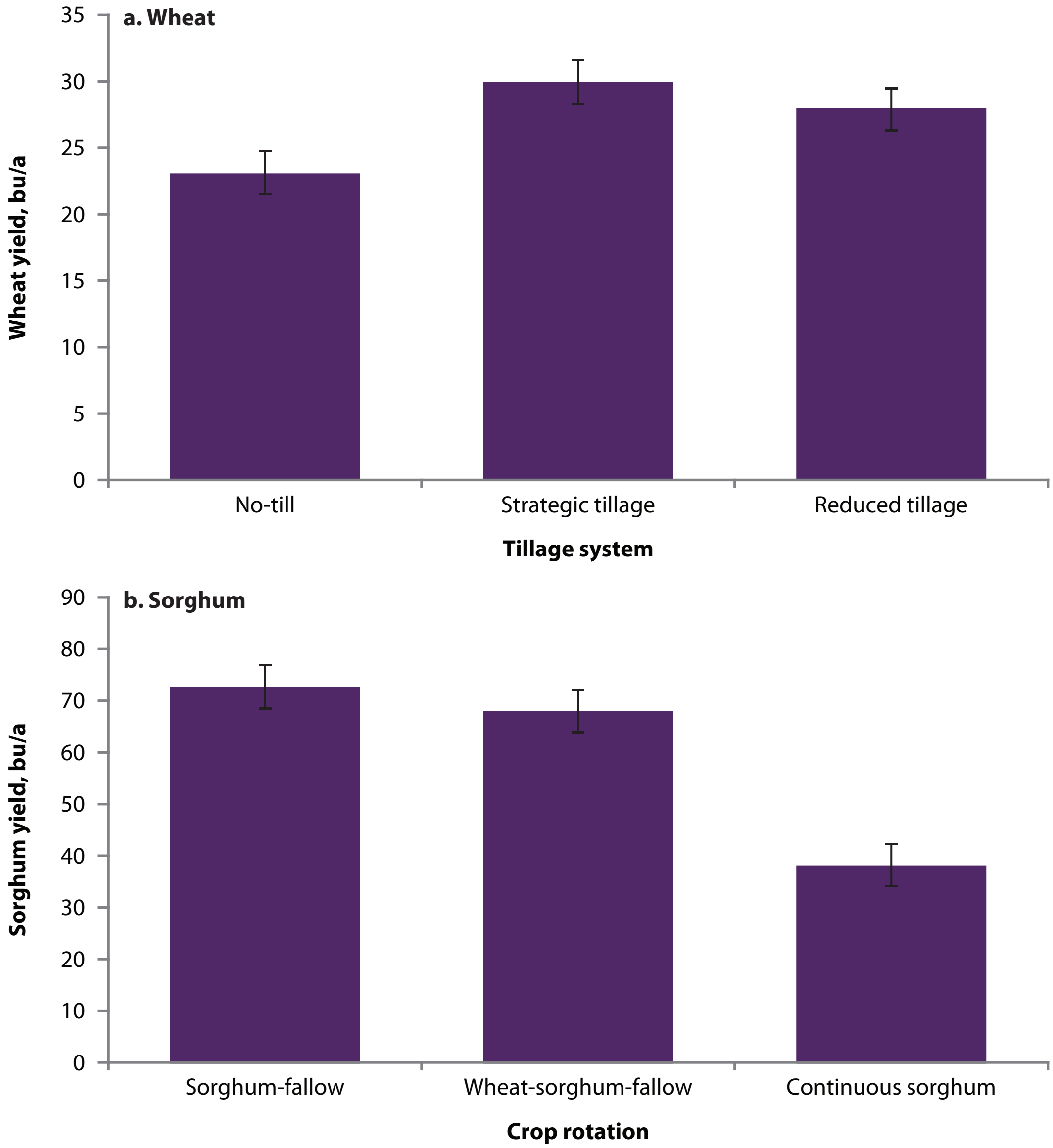

Figure 3. Winter wheat (a) and grain sorghum (b) grain yield as affected tillage system. Data are averaged across three crop rotations, 2 years, and three replications (n = 18).