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Research Article

Influence of No-Tillage on Soil Organic Carbon, Total Soil Nitrogen, and Winter Wheat (*Triticum aestivum* L.) Grain Yield

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No-tillage (NT) can improve soil properties and crop yield. However, there are contrasting reports on its benefits compared to conventional tillage (CT). Dataset (2003–2018) from long-term continuous winter wheat (*Triticum aestivum* L.) experiments 222 (E222) at Stillwater and 502 (E502) at Lahoma in Oklahoma, USA, established in 1969 and 1970, respectively, was used. Both experiments were managed under CT until 2010 and changed to NT in 2011. In each tillage system, treatments included nitrogen (N) rates at E222 (0, 45, 90, and 135 $kg{\cdot}N{\cdot}ha^{-1}$) and E502 (0, 22.5, 45, 67, 90, and 112 $kg{\cdot}N{\cdot}ha^{-1}$). The objective was to determine the change in wheat grain yield, soil organic carbon (SOC), and total soil nitrogen (TSN) associated with the change to NT. Grain yield was recorded, and postharvest soil samples taken from 0–15 cm were analyzed for TSN and SOC. Average TSN and SOC under NT were significantly above those under CT at both locations while grain yield differences were inconsistent. Under both tillage systems, grain yield, TSN, and SOC increased with N rates. At E222, grain yield, TSN, and SOC under NT were 23%, 17%, and 29%, respectively, more than recorded under CT. At E502, grain yield was lower under NT than CT by 14% while TSN and SOC were higher by 11% and 13%, respectively. Averaged over experimental locations, wheat grain yield, TSN, and SOC were 5%, 14%, and 21%, respectively, higher under NT compared to CT. Therefore, NT positively influenced grain yield, TSN, and SOC and is likely a sustainable long-term strategy for improving soil quality and crop productivity in a continuous monocropping system.

1. Introduction

The depletion of soil resources as a result of poor production practices and the subsequent decline in crop yields has resulted in a search for sustainable approaches in crop production. No-tillage (NT) production systems, synonymous with zero tillage or conservation agriculture and sometimes minimum tillage (MT), is one of these sustainable crop production approaches sought by scientists around the world [1]. This approach has gained attention in the past years, and there is a growing trend for adoption by crop producers globally. Derpsch et al. [2] reported a world adoption rate of 6 M ha per year between 1999 and 2009 where field crop area grew to 111 M ha. By 2013, the land area under NT increased to 157 M ha, equivalent to approximately 11% of the total field production area [3]. In 2016, the total global land area increased to 180 M ha, corresponding to approximately 12.5% [4]. The global increase in the rate of adoption and expansion of land area under NT is a result of numerous benefits associated with this farming practice. Generally, the benefits of NT originate from the three main principles: reduced soil disturbance, improved soil cover from crop residues, and increased species diversity through crop rotation [5, 6]. Therefore, the improvement in soil's chemical and physical properties such as SOC, total porosity, and water holding capacity, among others under NT follow these principles [7].

Soil organic carbon and TSN are indicators of soil quality and provide structural stability to the soil matrix. However, there is a significant reduction in the rate of buildup and possible depletion under the CT system [8, 9]. Halvorson et al. [10] reported a decreasing pattern in SOC as NT < MT < CT where the most SOC is retained under NT. Practices that limit soil disturbance and encourage residue retention help in the restoration of these important soil quality parameters. Farooq and Siddique [1] asserted that NT increases SOC content by adding fresh plant residues that protect the enriched topsoil from rapid chemical and physical weathering. On sloping terrain, the implementation of NT leads to SOC accumulation by reducing the rate of severe soil erosion [11]. The retention of the residue on the surface of the soil through NT also helps in moderating temperature and moisture fluctuations. These abiotic factors are in turn responsible for controlling the rate of accumulation of SOC.

In addition to the improvement of soil structural stability, NT plays an important role in the reduction of production costs through reduced labor requirements for land tilling. It is important to note, however, that this approach requires a particular type of equipment for seed drilling [5]. This could be a setback for farmers in developing countries that are yet to adopt the use of such implements. Additionally, in developed countries, the initial cost of switching implements or reconfiguring the existing equipment to accommodate for NT is high, and this seems to be a reason why producers are sometimes reluctant to adopt the practice [12].

Other NT benefits relating to the improvement in crop productivity may depend on the specific production environment. For instance, Devita et al. [13] reported that the contribution of NT to grain yield improvement may be realized in environments where precipitation is less than 300 mm per year. According to their findings, NT may not significantly produce higher grain yield compared to the CT system in areas with adequate precipitation. This is especially true if moisture conservation and improved water infiltration are important [14, 15]. Hansen et al. [16] added that NT is a key management strategy with the apparent temporal and spatial climate variability. Furthermore, grain yield improvement depends on the length of production under NT practice [17]. Much as structural stability could be realized under NT within a short-term production period, grain yield benefits under NT are possible after long-term crop production cycles.

Some researchers report decreases in root growth and grain yield under NT for many reasons. Soil compaction, which decreases soil aeration and water infiltration, can in some cases reduce crop yield under NT [18]. The decrease in crop yield can also result from reduced N use efficiency of surface-applied urea due to volatilization losses [19]. The use of slow-release N fertilizers such as sulfur-coated urea and delayed urea application may improve the efficiency of fertilizer N under NT. Arvidsson et al. [20] reported a 10% decline in crop yield under NT relative to the CT system. This decrease in yield was attributed to poor crop establishment due to improper seedbed preparation that they referred to as "lack of seedbed."

In addition to yield reduction, NT has also been scrutinized for the emergence of herbicide-resistant weeds as a result of overdependence on the use of chemicals [21]. The latter can increase the risk of subsurface flow of chemicals that can increase the potential for environmental pollution. Therefore, the agronomic and environmental impact or the success of NT is environment-specific, and the improvement in soil's chemical and physical properties under NT translates to the improvement in crop yield after long-term implementation of this practice. Data used in this study were taken from two long-term experiments established in the 1960s under CT practice at the time when limited research reports on the importance of NT practice were available. In the 1990s and early 2000, many research works indicated the superiority of NT over CT practice in improving crop yield and soil properties. This prompted a widespread adoption by farmers in the United States' Great Plains [16, 22] and was the main reason for the conversion of these long-term experiments from CT to NT. However, studies documenting the comparative benefits between CT and NT on TSN, SOC, and wheat grain yield from a long-term perspective in this region are scarce. Therefore, the objective of this study was to determine the change in wheat grain yield, SOC, and TSN associated with the conversion from CT to NT.

2. Materials and Methods

2.1. Site Description. This study used data from two long-term experiments: experiment 222 (E222) and experiment 502 (E502). The E222 trial was established in 1969 on a well-drained, deep, and slowly permeable Kirkland silt loam (fine, mixed, thermic Udertic Paleustoll) at the Agronomy Research Station in Stillwater, Oklahoma, USA, with an altitude of 272 masl. Experiment 502, established in 1970, is located on a well-drained, deep, and moderately permeable Grant silt loam (fine-silty, mixed, thermic Udic Argiustoll) at the North Central Research Station in Lahoma, Oklahoma, USA, with an altitude of 396 masl. For both experimental sites, total rainfall and average air temperature were computed for the winter wheat growing periods (October–June) for each year reported (Figure 1). Comparisons were made for varieties planted under both tillage systems to determine whether or not significant differences existed between the tillage systems with the same wheat variety at both sites (Figure 2).

2.2. Experimental Design and Management. The experimental design at E222 was a randomized complete block with thirteen treatments and four replications. Only 4 of the treatments, 1, 2, 3, and 4 with 0, 45, 90, and 135 $kg{\cdot}N{\cdot}ha^{-1}$, respectively, were used for this report (Table 1). Each of these treatments had fixed phosphorus (P) and potassium (K) rates of 29 and 37 $kg{\cdot}ha^{-1}$, respectively. Fertilizer N was applied as urea (46-0-0) preplant. The treatment with the maximum N rate (135 $kg{\cdot}ha^{-1}$) was split, 67.5 $kg{\cdot}ha^{-1}$ preplant and another 67.5 $kg{\cdot}ha^{-1}$ applied midseason. Fertilizer P and K were applied preplant as triple superphosphate (0-22-0) and potassium chloride (0-0-52), respectively. The

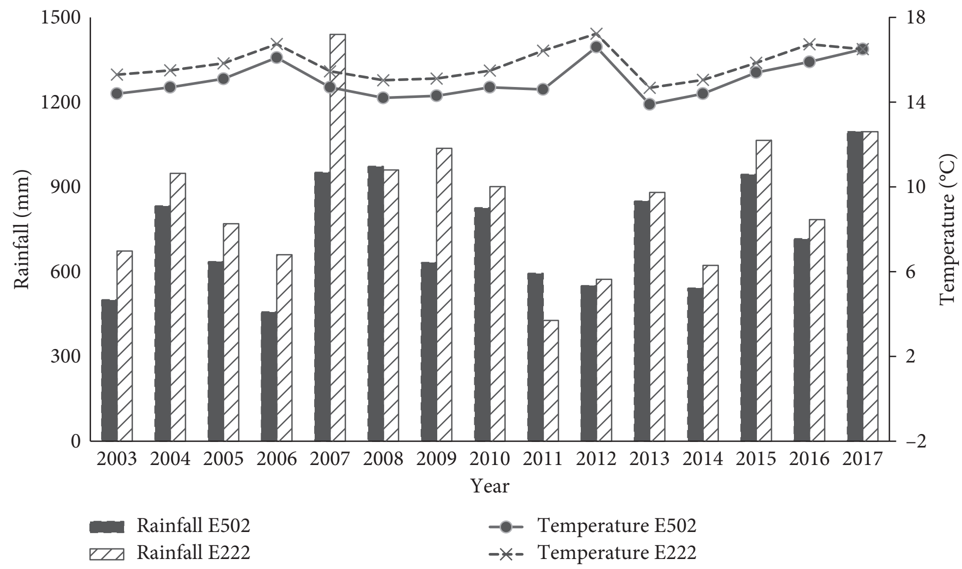

Figure 1: Total rainfall (October–June) and average air temperature (October–June) at E222 (Stillwater) and E502 (Lahoma), Oklahoma, USA, 2003–2017.

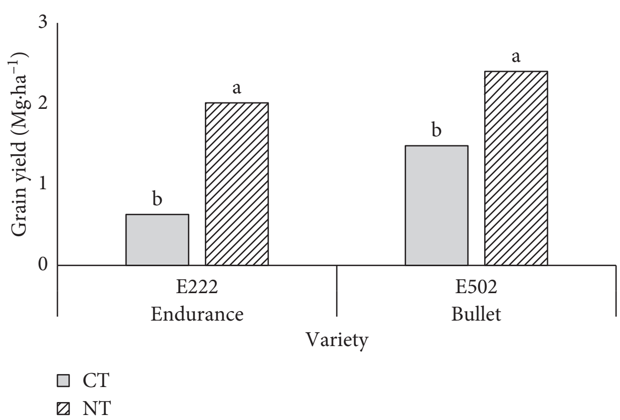

Figure 2: Average wheat grain yield for varieties planted under CT (conventional tillage) and NT (no-tillage) at E222 (Stillwater) and E502 (Lahoma), Oklahoma USA; different letters indicate significant differences between varieties at each site at $p < 0.05$; Tukey's HSD test.

Table 1: Treatment arrangement with preplant N, P, and K rates at E222 (Stillwater) and E502 (Lahoma), Oklahoma, USA.

Treatment number	N rate ($kg{\cdot}N{\cdot}ha^{-1}$)	P rate ($kg{\cdot}P{\cdot}ha^{-1}$)	K rate ($kg{\cdot}K{\cdot}ha^{-1}$)
	E222		
1	0	29	37
2	45	29	37
3	90	29	37
4	135[†]	29	37
	E502		
2	0	20	56
3	22.5	20	56
4	45	20	56
5	67	20	56
6	90	20	56
7	112	20	56

N = nitrogen applied as urea (46-0-0); P = phosphorus applied as triple superphosphate (0-22-0); K = potassium applied as potassium chloride (0-0-52). [†]Split applied with 67 $kg{\cdot}N{\cdot}ha^{-1}$ preplant and 67 $kg{\cdot}N{\cdot}ha^{-1}$ midseason.

design at E502 was a randomized complete block with fourteen treatments and four replications. For this report, however, only six treatments, 2, 3, 4, 5, 6, and 7 with 0, 22.5, 45, 67, 90, and 112 $kg{\cdot}N{\cdot}ha^{-1}$, respectively, were used (Table 1). For each of these treatments, P and K were applied at fixed rates of 20 and 56 $kg{\cdot}ha^{-1}$, respectively. Nitrogen, P, and K were applied preplant as urea (46-0-0), triple superphosphate (0-22-0), and potassium chloride (0-0-52), respectively. Both E222 and E502 were established as a continuous winter wheat-summer fallow under the CT system until 2010 where disc harrow and chisel plough were used in the experimental fields prior to planting seeds. Presently, they are managed under NT with no cultivation prior to seed drilling, and all residues are left on the soil surface after harvest [23]. Under the NT practice, Roundup (glyphosate) and WeedMaster (dicamba: 12.4% and 2,4-D: 35.7%) herbicides were applied every year at a rate of 1-2 $L\ ha^{-1}$, depending on the weed pressure. Winter wheat seeds of 100 $kg{\cdot}ha^{-1}$ in weight were drilled using the Great Plains 2010 Drill (Great Plains Ag, Salina, Kansas, USA). Planting dates varied from one year to another, but seeds were generally drilled in October (1st to 30th) of each year reported in this study (2003–2018). Both experimental fields were managed under rain-fed conditions with no irrigation water applied.

2.3. Sampling and Sample Processing. Winter wheat grain yield data used in this report were obtained over eight years for each tillage system from 2003 to 2010 and from 2011 to 2018 under CT and NT, respectively. Experimental plots were harvested at maturity using a Massey Ferguson 8XP self-propelled combine. Grain yields were adjusted to 12.5%

moisture content. Data on SOC and TSN were available for only four years each under CT and NT, not eight years as reported for grain yield. Under CT, data were obtained from 2007 to 2010 while under NT, data were obtained from 2011 to 2014. In July of each year, 15–20 postharvest soil cores were collected from 0–15 cm soil depth and composited for each treatment. These samples were oven-dried for 48 hours at 65°C and later ground to pass a 1 mm sieve. The determination of SOC and TSN was completed using the LECO Truspec CN dry combustion analyzer [24]. The LECO CN 628 dry combustion analyzer was used. For each sample, 200 mg of soil by treatment and replication was weighed, wrapped in aluminum foil, and combusted at 950°C.

2.4. Statistical Analysis. Data were analyzed using the SAS statistical software package [25]. The GLM procedure was used to conduct the analysis of variance appropriate for a randomized complete block design for grain yield, TSN, and SOC. Single-degree-of-freedom orthogonal contrasts were used to compare grain yield, TSN, and SOC treatment means from CT and NT [26, 27]. To associate grain yield with soil quality parameters, the relationships between grain yield and TSN as well as grain yield and SOC were evaluated using the SAS PROC REG procedure [25].

3. Results

3.1. Wheat Grain Yield. Analysis of variance showed an overall significant difference ($p < 0.05$) in mean grain yield between CT and NT at E222 (Table 2). For specific N rates, no significant ($p > 0.05$) difference was observed between CT and NT in the check plot (0 kg·N·ha^{-1}). However, significant ($p < 0.05$) grain yield differences were observed at 45, 90, and 135 kg·N·ha^{-1}, and yields were 30, 21, and 21% higher under NT than seen under the CT system, respectively. Generally, grain yield across all treatments was 23% higher under NT than that observed under CT. Grain yield increased with N rates under both practices. Although the increase was generally higher under NT for all N application rates, the trend was similar to that observed under CT (Figure 3(a)).

At E502, overall results showed a significant difference ($p < 0.05$) in grain yield mean values between CT and NT (Table 3). When specific and equal N rates under CT and NT were in contrast to each other, no grain yield differences were observed at 0, 22.5, 45, 67, and 90 kg·N·ha^{-1}. However, a significant difference ($p < 0.05$) was observed with an application rate of 112 kg·N·ha^{-1} where grain yield under CT was 0.7 Mg·ha^{-1} higher than recorded under NT. Generally, average wheat grain yield across treatments was 14% higher under CT than NT. This result did not mirror the observation at E222 where grain yields at all N rates were higher under NT than under the CT system.

Overall analysis indicates significant differences ($p < 0.05$) in grain yield of wheat varieties planted at both sites. Varieties that were planted under both tillage systems also showed significant differences in grain yield. At E502, the variety "Bullet" yielded significantly higher under NT than CT (Figure 2). Similarly, comparison of varieties at E222 showed that "Endurance," planted under both tillage systems, yielded significantly higher under NT than under CT (Figure 2). The influence of tillage system was therefore independent of wheat varieties used in this study.

Table 2: Treatment means for grain yield, TSN, and SOC and single-degree-of-freedom orthogonal contrasts between CT and NT treatments at E222 (Stillwater), Oklahoma, USA, 2003–2018.

Treatment	Tillage	N rate (kg·ha^{-1})	Grain yield (Mg·ha^{-1})†	TSN (g·kg^{-1})‡	SOC (g·kg^{-1})‡
		Treatment means			
1	CT	0	1.32	0.80	8.53
2	CT	45	1.53	0.88	9.14
3	CT	90	1.94	0.91	9.61
4	CT	135	2.04	0.97	10.05
CV (%)			49.4	13.5	8.2
1	NT	0	1.70	0.99	12.07
2	NT	45	2.17	1.03	13.15
3	NT	90	2.45	1.11	13.61
4	NT	135	2.59	1.15	14.02
CV (%)			42.3	24.2	38.7
		Contrast p value			
1	CT1 vs. NT1	0	0.1074	0.0247	0.0257
2	CT2 vs. NT2	45	0.0060	0.0705	0.0119
3	CT3 vs. NT3	90	0.0281	0.0180	0.0119
4	CT4 vs. NT4	135	0.0209	0.0345	0.0127
Average	CT vs. NT		<0.0001	<0.0001	<0.0001

CV = coefficient of variation; CT = conventional tillage; NT = no-tillage; TSN = total soil nitrogen; SOC = soil organic carbon; †treatment means for grain yield were obtained under CT (2003–2010) and NT (2011–2018); ‡treatment means for TSN and SOC were obtained under CT (2007–2010) and NT (2011–2014).

3.2. Total Soil Nitrogen. Total soil nitrogen at E222 was significantly different ($p < 0.05$) between CT and NT at 0 kg·N·ha^{-1} where the latter was 19% higher than the former. At 45 kg·N·ha^{-1}, no significant difference ($p > 0.05$) in TSN accumulation was observed between CT and NT. Nevertheless, significant differences ($p < 0.05$) were observed at 90 and 135 kg·N·ha^{-1} where TSN was 18 and 16% higher under NT than observed under CT at the respective N rates. Considering average values across treatments, TSN was 17% higher under NT than recorded under CT. A pattern of buildup in TSN was observed for both practices (Figure 3(c)). Under NT, positive linear relationships between TSN and grain yield were observed across N rates (Table 4).

For E502, N application rates of 0, 22.5, 45, and 67 kg·N·ha^{-1} at E502 did not result in a significant difference in TSN between CT and NT. Nonetheless, significant differences ($p < 0.05$) in TSN between NT and CT were seen at 90 and 112 kg·N·ha^{-1} where the NT produced 15 and 12%

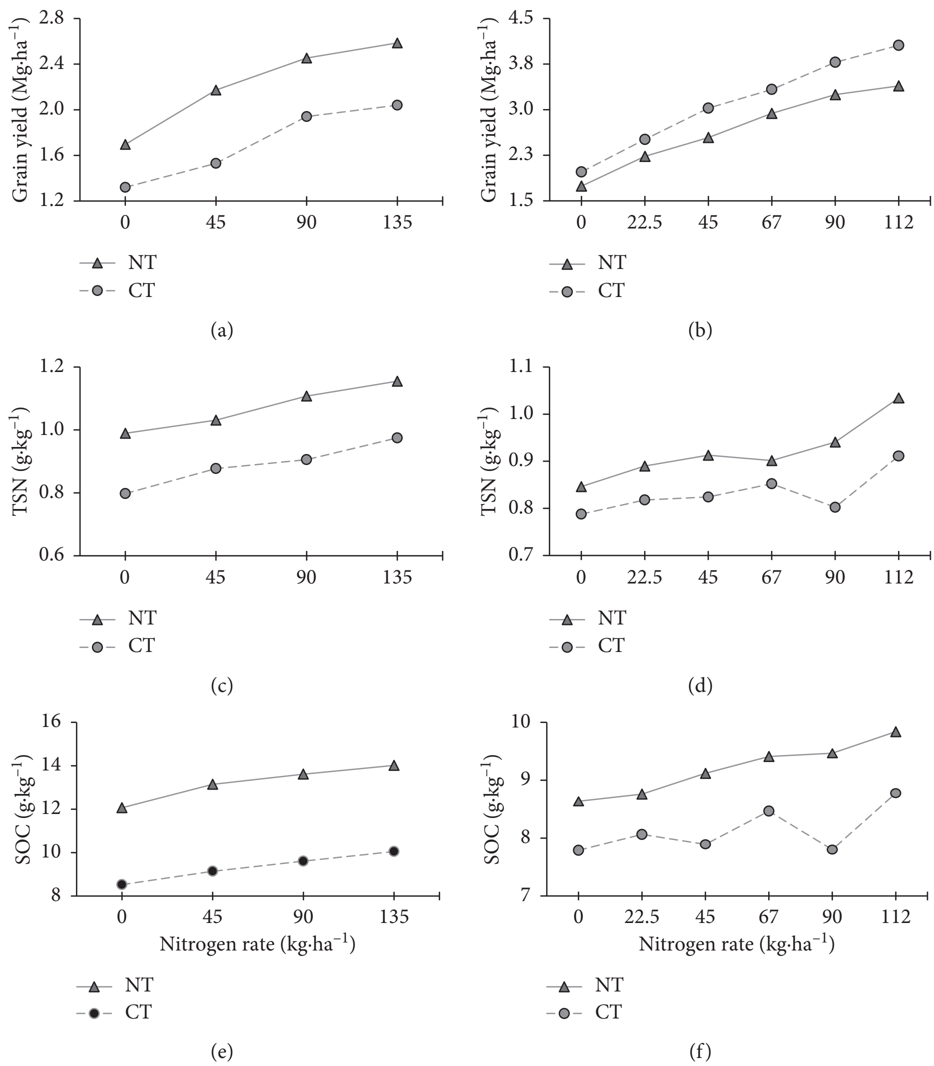

Figure 3: Changes in grain yield at E222 (a) and E502 (b); TSN at E222 (c) and E502 (d); SOC at E222 (e) and E502 (f) as influenced by different fertilizer rates under NT (no-tillage) and CT (conventional tillage).

higher TSN than for CT. Averaged across treatments, NT had 11% higher TSN than CT. The observation at E502 is similar to that at E222 although the latter was 6% higher than the former. Unlike E222, the slopes of the linear relationship between TSN and grain yield under NT were negative for each N rate at E502 (Table 4).

3.3. Soil Organic Carbon. Significant differences ($p < 0.05$) in the buildup of SOC between CT and NT were observed in all treatments at E222. Soil organic carbon was 29, 30, 29, and 28% higher under NT than recorded under CT at 0, 45, 90, and 135 kg·N·ha^{-1}, respectively. This result does not show any pattern of percentage difference in the SOC buildup under NT with N rates although a nonsignificant trend for increased SOC with applied N was present for both practices (Figure 3(e)). It is also evident that the increase was higher under NT than CT. Averaged across treatments, SOC under NT was 29% higher than that recorded for CT. Under NT, positive linear relationships between SOC and grain yield were observed across N rates (Table 4).

At E502, SOC accumulation between CT and NT was significantly different ($p < 0.05$) at all N application rates. At treatment levels of 0, 22.5, 45, 67, 90, and 112 kg·N·ha^{-1}, SOC under NT was 10, 8, 14, 10, 18, and 11% higher, respectively, compared to that under CT. Averaged across all treatments, SOC was 13% higher under NT than under CT. This result mirrored the observation at E222 with an overall significant difference between NT and CT under all N rates. However, the overall difference was 16% higher at E222 than under E502. The linear relationships for each N rate between SOC and grain yield under NT had negative slopes at E502 and did not mirror observations at E222 (Table 4).

4. Discussion

4.1. Wheat Grain Yield. Results from the present study showed that grain yield under NT was significantly higher than that under the CT system. However, the yield benefit accrued under NT was not consistent across experimental sites. Overall, grain yield under NT was higher than that

Table 3: Treatment means for grain yield, TSN, and SOC and single-degree-of-freedom orthogonal contrasts between CT and NT treatments at E502 (Lahoma), Oklahoma, USA, 2003–2018.

Treatment	Tillage	N rate (kg·ha^{-1})	Grain yield (kg·ha^{-1})†	TSN (g·kg^{-1})‡	SOC (g·kg^{-1})‡
			Treatment means		
2	CT	0	1.98	0.79	7.79
3	CT	22.5	2.51	0.82	8.06
4	CT	45	3.03	0.82	7.89
5	CT	67	3.33	0.85	8.47
6	CT	90	3.78	0.80	7.80
7	CT	112	4.06	0.91	8.78
CV (%)			40	13.7	13.9
2	NT	0	1.74	0.85	8.64
3	NT	22.5	2.23	0.89	8.76
4	NT	45	2.54	0.91	9.12
5	NT	67	2.94	0.90	9.41
6	NT	90	3.25	0.94	9.47
7	NT	112	3.39	1.03	9.84
CV (%)			35	23.8	7.6
			Contrast p value		
2	CT2 vs. NT2	0	0.3933	0.3471	0.0120
3	CT3 vs. NT3	22.5	0.3095	0.2469	0.0381
4	CT4 vs. NT4	45	0.0802	0.1545	0.0003
5	CT5 vs. NT5	67	0.1511	0.4287	0.0052
6	CT6 vs. NT6	90	0.0588	0.0269	<0.0001
7	CT7 vs. NT7	112	0.0178	0.0486	0.0017
Average	CT vs. NT		0.0002	0.0006	<0.0001

CV = coefficient of variation; CT = conventional tillage; NT = no-tillage; TSN = total soil nitrogen; SOC = soil organic carbon; †treatment means for grain yield were obtained under CT (2003–2010) and NT (2011–2018); ‡treatment means for TSN and SOC were obtained under CT (2007–2010) and NT (2011–2014).

Table 4: Summary of relationships between wheat grain yield, TSN, and SOC under NT at E222 (Stillwater) and E502 (Lahoma), Oklahoma, USA, 2007–2014.

Treatment	N rate (kg·ha^{-1})	TSN vs. grain yield			SOC vs. grain yield		
		p value	R^2	Equation	p value	R^2	Equation
				E222			
1	0	0.0036	0.59	$y = 1777.8x - 727$	0.0076	0.53	$y = 412.15x - 2946$
2	45	0.0058	0.55	$y = 2183.2x - 931$	<0.0001	0.95	$y = 615.2x - 5020$
3	90	0.2087	0.15	$y = 1139.8x + 376$	0.0029	0.6	$y = 418.36x - 2900$
4	135	0.0951	0.25	$y = 1544.1x - 223$	0.0206	0.43	$y = 402.05x - 2840$
				E502			
2	0	0.0154	0.35	$y = -2732.5x + 4280$	0.2003	0.11	$y = -477.8x + 6094$
3	22.5	0.0008	0.56	$y = -3659.2x + 5745$	0.0491	0.25	$y = -741.33x + 8983$
4	45	0.004	0.46	$y = -3571.1x + 6273$	0.0015	0.53	$y = -1455.9x + 16290$
5	67	0.0053	0.42	$y = -5196.7x + 7919$	0.1457	0.14	$y = -734.62x + 10194$
6	90	0.0041	0.54	$y = -5344.8x + 8852$	0.3068	0.09	$y = -1059.8x + 13849$
7	112	0.0133	0.44	$y = -4621.5x + 9196$	0.0285	0.37	$y = -1265x + 16803$

E502 = experiment 502; E222 = experiment 222; $n = 16$ for each treatment; NT = no-tillage; TSN = total soil nitrogen; SOC = soil organic carbon.

under the CT system by 5% when averaged across locations. Although higher for NT, a trend for increased grain yield with N rates was observed at both sites and under both systems. The increase in grain yield with fertilizer N under NT was most likely due to improved N utilization. This is in agreement with the work by Triplett and Dick [28] reporting that NT improved fertilizer use efficiency. Improved soil structural stability under NT coupled with increases in potential mineralizable N could have had an impact on grain yield. Doran et al. [29] reported between 20 and 101 kg·ha^{-1} as potentially mineralizable N under NT compared to the CT system. In a maize-wheat sequence, Ghuman and Sur [30] observed an overall grain yield advantage of NT over CT, but noted that yields were much higher with the application of residue mulch of 3 Mg·ha^{-1} from the previous season. From another perspective, Devita et al. [13] noted that the overall grain yield advantage for NT over CT was realized in environments where precipitation was less than 300 mm per year. In the current study, however, the average annual rainfall at both locations was above 300 mm. Over the study period, the average annual rainfall was 715 mm and 856 mm at E502 and E222, respectively. With average grain yield comparatively lower at E222 than at E502, this demonstrates the advantage of the NT system in relatively low yielding environments. It is important to note that the gap between NT and CT was wider than observed at E502, again illustrating the positive impact of a NT system in low yielding environments. Overall, comparisons of varieties planted under both tillage systems showed that wheat grain yield under NT was greater than that under CT.

4.2. Total Soil Nitrogen. Total soil nitrogen at both locations increased with an increase in N applied for both CT and NT when averaged over treatments, consistent with several research reports [31–35]. Ortas et al. [36] explained that an increase in TSN with increased N fertilizer rate was a result of improved plant biomass production with decreased C : N ratio. Even under CT, TSN increased with increase in N applied. In a long-term continuous CT system, Raun et al. [34] also observed an increase in TSN with increased fertilizer N rates. Generally, similar trends for increased TSN were seen for both systems although TSN under NT was significantly higher than that under CT. The current study showed that TSN was 14% higher for NT when compared to CT, and that was similar to a report by Mikha and Rice [37]. According to Havlin et al. [38], increased TSN under NT was greater for crop rotation practices with high surface residue compared to CT even at limited or no fertilizer N application. Malhi and Kutcher [39] also reported higher TSN under NT compared to CT when crop residue was returned to the soil surface. By design, NT automatically leaves the residue on the soil surface [40]. Consistent with these reports, the current study indicates that high fertilizer N input under NT improves TSN buildup better than under CT although positive linear relationships with grain yield were not consistent across locations.

4.3. Soil Organic Carbon. In general, SOC was significantly higher under NT than under the CT system at all experimental sites. The tendency of SOC to increase with N rates was observed under both systems. This is consistent with a report by Lafond et al. [41] who observed high SOC under high levels of N application. The high SOC under NT could be a result of increased biomass production associated with high N rates. At high N rates, increased biomass production compared to the control treatment with no N applied increases the possibility of surface buildup of SOC under NT [23, 33]. In a long-term study, Havlin et al. [38] also reported greater SOC under NT compared to CT. However, the authors indicated that there was a tendency for soil to accumulate more SOC under a rotation system compared to continuous monocropping because of increased species diversity. The current study, under continuous monocropping practice, shows an average of 21% more SOC under NT than CT. From another perspective, the rate of SOC accumulation is likely dependent on how long production has taken place under NT. For instance, Lafond et al. [41] reported significantly higher SOC under long-term NT (39 years) compared to short-term NT (9 years). In their study, long-term NT produced 17% more SOC than short-term NT from the 0–15 cm soil layer, while no differences were observed between samples obtained from a 15–30 cm soil depth. In the present study, the inconsistent positive linear relationships between NT and grain yield could be due to relatively shorter production cycle (8 years) under this practice or just a result of differences in the production environment. This implies that there will be major improvements in this parameter after 15 or 20 years. Dolan et al. [32] reported over 30% more SOC in a 0–20 cm soil layer under NT than CT. Under native prairie or long-term NT, the residue decomposition rate is slow, and surface accumulation explains the high SOC at 0–15 cm. The CT practice aerates the soil system allowing for decomposition to take place much faster. In the process, more carbon is oxidized. Therefore, producers have to practice NT on a long-term basis in order to realize a significant improvement in soil quality and crop yield.

5. Conclusion

The current study examined the benefits of changing from CT to NT in a continuous winter wheat-summer fallow practice. Generally, the results showed an overall positive influence of NT on winter wheat grain yield, TSN, and SOC. However, the extent to which NT impacted these parameters varied with experimental locations, and they were more positive in low yielding environments. Results averaged over experimental locations and treatments indicate a 5% yield benefit under NT over CT. Total soil N and SOC from a 0–15 cm soil depth under NT were higher than those under CT by 14% and 21%, respectively. The small (5%) increase in grain yield could be due to a shorter production cycle (8 years) under NT. This is consistent with a conclusion by Lafond et al. [41] that soil quality parameters and crop yield are additive under NT. Therefore, compared to CT, NT was a better alternative crop production practice and is likely a sustainable long-term strategy for improving soil quality and crop productivity in a continuous monocropping system.

Data Availability

The data used for this study is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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