Long-Term Soil Organic Carbon as Affected by Tillage and Cropping Systems

G. E. Varvel*
USDA-ARS
and
Dep. of Agronomy
Univ. of Nebraska
Lincoln, NE 68583

W. W. Wilhelm
USDA-ARS (deceased)

The use of conservation tillage systems for corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] production has increased in recent years because of several factors including their potential to reduce losses or sequester soil organic C (SOC). This study evaluated the effects on SOC of three cropping systems (continuous corn [CC], continuous soybean [CSB], and soybean–corn [SB-C]) in six primary tillage systems (chisel, disk, plow, no-till, ridge-till, and subtill) under rainfed conditions in southeastern Nebraska. Soil samples were collected in depth increments of 0 to 7.5, 7.5 to 15, and 15 to 30 cm in the fall of 1989 and 2004 after harvest and analyzed for SOC. No significant differences in SOC concentrations were obtained among tillage treatments in any depth in a partial sampling of a study that was done in 1989. Tillage treatment and cropping system both significantly affected SOC concentrations and reserves at all depths in 2004, but only bulk density at a few depths. No-till SOC reserves ranged from 4.8 to 11.6 Mg ha^{-1} greater than SOC reserves in the other tillage treatments in the 0- to 30-cm depth. Similarly, SOC concentrations and reserves were greatest in CC and least in CSB, with intermediate values for SB-C in all tillage systems. Soil organic C levels were maintained or even increased in all tillage systems; however, the greatest increases were obtained in systems with the least amount of soil disturbance, which strongly supports the adoption and use of conservation tillage systems for soil sustainability.

Abbreviations: CC, continuous corn; CSB, continuous soybean; SB-C, soybean–corn; SOC, soil organic carbon.

Various types of conservation tillage systems are prevalent throughout the Midwest and western Corn Belt. According to Wilhelm and Wortmann (2004), the area planted without preplant tillage in the United States was estimated at 21 × 10^6 ha in 2000 (approximately 38% of U.S. cropland). There are several benefits of practicing conservation tillage, a system of crop production with little, if any, tillage that increases the crop residue that remains in the field after harvest through planting. These benefits, including natural recycling of crop residues, reduced costs, soil protection, water conservation, increased yield, and increased profit, have escalated the adaptation of these systems.

Another important reason for utilizing some form of conservation tillage is to conserve or potentially increase SOC. In conventionally tilled long-term cropping system experiments, Pikul et al. (2008) and Varvel (2006) both found that even with increased cropping system diversity, SOC levels were either reduced or at best maintained after 15 to 20 yr of cropping. Recent literature reviews by Johnson et al. (2006) and Wilhelm et al. (2007) found that in most cropping systems utilized for corn production in the United States, some form of conservation tillage is necessary if producers hope to maintain or increase SOC levels. This is especially critical in those areas of the country where corn residues are being harvested for either livestock roughage or the production of cellulosic ethanol (Wilhelm et al., 2007).

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*Corresponding author (Gary.Varvel@ars.usda.gov).
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There are several additional reasons for adopting practices that maintain or increase SOC levels. Soil organic matter also affects many soil properties, including aggregate stability, water holding capacity, cation exchange capacity, nutrient cycling, and many others factors critical to soil function. According to Sparling et al. (2006), crop yield and environmental services (C and N sequestration) were greater for soils with greater SOC levels. Brejda et al. (2000) also identified SOC as one of the most sensitive indicators of soil quality in the central and southern High Plains. In this context, soil quality has been defined as "the capacity of a soil to function within ecosystem and land use boundaries, to sustain biological productivity, maintain environmental quality, and promote plant and animal health" (Doran and Parkin, 1994). In addition, Wienhold et al. (2006) noted that improved soil quality in cropping system studies throughout the Great Plains and western Corn Belt areas was usually the result of increased SOC levels.

In an extensive review of 67 long-term agricultural experiments from around the world, West and Post (2002) concluded that conservation practices generally resulted in SOC sequestration. They noted that SOC sequestration tended to increase as soil disturbance decreased and also as cropping system diversity increased. Their general conclusions were that changes in cropping system diversity did not increase SOC sequestration as much as switching to reduced or no- till systems. West and Post (2002) hypothesized that changes in SOC will initially be caused by reductions in the amount of tillage and a coincident decrease in SOC decomposition. Further long-term (40–60-yr) increases in SOC will probably be caused by increased cropping system diversity and changes in residue inputs and composition (West and Post, 2002). As stated by Lal (2004), soil organic matter content, which is critical to crop production functions of the soil, increases slowly in response to improved management. This slow response to crop and soil management practices and the variable nature of SOC measurements requires a significant amount of time before the direction of SOC change can be determined.

A long-term tillage and cropping system experiment provides an opportunity to partially test the hypotheses of West and Post (2002) and perhaps substantiate the comments of Lal (2004). Our objective was to evaluate the long-term effects of tillage and crop management systems on SOC in a rainfed experiment in the western Corn Belt.

MATERIALS AND METHODS

This experiment was initiated in 1980 at the Rogers Memorial Farm on a silty clay loam soil (deep, moderately well-drained, upland Sharpsburg soil formed in loess; a fine, smectitic, mesic Typic Argiudoll) approximately 19 km east of Lincoln, NE, under natural rainfall conditions.

The experiment was originally designed as a randomized complete block (six replications) with six tillage treatments. The tillage treatments were chisel plow (chisel), tandem disk (disk), moldboard plow (plow), no-till, ridge-till, and subsoil tillage (subtill). Corn was the only crop in the experiment for the first 6 yr. The original design was then modified in 1986 to a randomized complete block design with a split-plot arrangement of cropping systems. Subplot treatments were CC, CSB, and a 2-yr SB-C rotation, with each phase present each year. Whole tillage plots were 18.3 (24, 0.76-m rows) by 22.9 m. Subplots were 4.6 (six, 0.76-m rows) by 22.9 m.

After grain harvest from 1980 to 1999, corn stover was chopped and the chisel, plow, and subtill treatments were applied. The depth of tillage was approximately 25 cm for the chisel and plow treatments and 36 cm for the subtill treatment. Chisel shanks with straight points at a 25-cm spacing were used. The subsoil implement (Blu-jet Subtiller, Thurston Manufacturing Co., Thurston, NE) was equipped with standard shanks and fall-till points at a 76-cm spacing and positioned to operate between the planted rows. Residue was chopped in spring for the disk, no-till, and ridge-till treatments. The depth of tillage for the disk treatment was approximately 10 cm. All tilled treatments were disked to <10-cm depth before planting (including the disk treatment, which was disked a second time). No primary or secondary preplant tillage operations were performed on the no-till or ridge-till treatments.

Corn was planted as weather and soil conditions allowed, usually in the first week of May. Soybean planting also depended on weather and soil conditions but was usually delayed by 1 wk after corn was planted. All crops were planted in 76-cm rows with a planter equipped with six Kinze Precision Placement, Style A row units (Kinze Manufacturing Co., Williamsburg, IA) with double-disk openers. Scalloped trash disks were adjusted to remove 3 to 5 cm of soil from the top of the ridge in the ridge-till treatment. In the no-till treatment, the trash disks were adjusted to move 0 to 2 cm of soil and the old crown from the row. All treatments, except no-till, were cultivated between the V5 and V8 growth stages (Ritchie et al., 1986) for corn and about the V5 growth stage (Ritchie et al., 1996) for soybean. At this time, or within 2 wk, ridges were formed in the ridge-till treatment. Both cultivating and ridging were done with a Buffalo row-crop cultivator (Fleischer Manufacturing Co., Columbus, NE).

Other cultural practices were similar to those used by local producers. Corn hybrids and soybean cultivars planted each year were chosen from commercially available selections adapted to the area. Planting population for corn ranged from 40,000 kernels ha^{-1} in the early years of the study to 58,000 kernels ha^{-1} since 1996. Soybean was planted at rates between 250,000 and 375,000 seeds ha^{-1}. Insecticides (which varied over the years) were applied to the corn at planting according to label procedures to reduce rootworm damage. For both corn and soybean, a combination of pre- and post-emergence herbicides (again, products varied over the years of the study), cultivation, and hand weeding were used to control weeds. Roundup-ready soybean cultivars have been planted since 1998. Roundup-ready corn hybrids have been planted since 1999. Nitrogen fertilizer was broadcast on the corn at 113 kg N ha^{-1} as NH_4NO_3 at about the V3 growth stage. Other plant nutrients were within acceptable levels for corn and soybean production.

The corn and soybean were harvested after reaching physiological maturity. Before 1998, the yield was determined by hand collecting all ears from an area of at least 9.3 m^2 within each corn plot. The grain was removed from the ears, weighed, and sampled for water content determination. During this period, soybean yield was determined by collecting all plants from an area of at least 4.6 m^2. The plant samples were air dried and the grain threshed from the stover. The grain was weighed and

sampled for water content determination. Since 1998, both corn and soybean grain was harvested with a plot combine to determine yield. Three central rows of each plot were sampled. All yield data were adjusted to a standard moisture content of 155 g kg^{-1} for corn and 130 g kg^{-1} for soybean.

Soil samples have been collected at various times during the experiment, but in some cases not all treatments or replications were sampled and in many cases the soil samples that were collected were not archived. Such was the case for the first set of soil samples analyzed for soil organic matter that we could utilize. These soil samples were taken in the fall of 1989 after the crops had been harvested and before fall tillage. The soil samples were taken from the first three replications in all tillage systems except for the ridge-till treatments. Samples were also taken only in those plots in each tillage system that had been in corn that summer, so the CSB and the soybean phase of the SB-C cropping systems were not sampled. Fifteen 1.8-cm-diameter cores were taken from each of the plots with hand probes to a depth of 30 cm, divided into 0- to 7.5-, 7.5- to 15-, and 15- to 30-cm increments, and composited by depth. No additional sampling information could be found, so bulk density could not be determined. All samples were air dried and then ground. These samples were then analyzed for soil organic matter utilizing the Walkley–Black method and then converted to SOC as described by Combs and Nathan (1998).

A more complete set of soil samples was taken in November of 2004 after the crops had been harvested and before fall tillage. Soil samples were taken in all plots in each tillage system and in all six replications. Fifteen 1.8-cm-diameter cores (three from the row and 12 from the interrow areas) were taken from each of the plots with hand probes to a depth of 30 cm, divided into 0- to 7.5-, 7.5- to 15-, and 15- to 30-cm increments, and composited by depth. All samples were air dried, ground to pass a 2-mm screen, and then analyzed for total C using an automatic C analyzer (Model 1500 CNS analyzer, Carlo Erba Strumentazione, Milan, Italy) interfaced with a continuous-flow mass spectrometer (Europa Scientific Ltd., Crewe, UK) according to the method described by Schepers et al. (1989). Total C equates to SOC because all soils were at a pH of 6.5 or lower. The soil bulk density was determined by using the volume and dry weights from the 15 sample cores from each subplot.

Soil organic C values were analyzed separately for each of the two sampling years. The values from the 1989 sampling were gravimetric values only and those values were compared among the five tillage systems sampled in the first three replications of the study. The crop rotations had only been implemented for 4 yr before this sampling and because only those plots that had been in corn during the 1989 growing season were sampled, no comparisons were made between the CC and corn after soybean in the SB-C cropping system. In 2004, when all subplots were sampled and bulk density data were collected, the total SOC reserves were calculated for each tillage system and rotation level combination at all depths and these values were also then summed to determine the total SOC reserves in the 0- to15- and 0- to 30-cm depths. All statistical analyses were performed using Proc GLM in Version 9.1 of SAS for Windows (SAS Institute, 2003).

Table 1. Soil organic C concentrations in the 0- to 7.5-, 7.5- to 15-, and 15- to 30-cm depths as affected by five of the six tillage treatments in plots in the first three replications planted to corn during the 1989 growing season at the Rogers Memorial Farm near Lincoln, NE.

Tillage		Soil organic C concentration		
		0–7.5 cm	7.5–15 cm	15–30 cm
		g C kg^{-1}		
Chisel		16.4	15.2	11.1
Disk		16.0	15.2	11.6
Plow		15.7	15.7	11.7
No-till		16.9	14.9	12.8
Subtill		14.7	13.8	10.8
CV, %		6.6	6.3	10.5
Source of variation	df		Mean squares	
Replication	2	23.6***	21.8***	46.7***
Tillage	4	2.0	1.6	1.7
Error	8	1.1	0.9	1.5

*** Significant at the 0.001 probability level.

RESULTS AND DISCUSSION

Soil organic C concentration results from soil samples taken in 1989 are shown in Table 1. As noted above, these SOC values were the earliest results found for this long-term study. No significant differences in SOC concentrations were found among the five tillage treatments in 1989 (Table 1). This result was unexpected given the range of tillage treatments included in the comparison, but because only half of the total replications were sampled, it appears that the variability in the results masked any actual differences that may have been present. Also, without bulk density measurements, comparisons throughout the total sampled depth are difficult. Soil C concentrations in Table 1, however, appear to possess a similar no-till > tilled systems trend as reported in other studies for the 0- to 7.5-cm depth (West and Post, 2002).

Soil C concentrations and bulk density values are shown in Table 2 for samples taken in the fall of 2004. In contrast to the results from 1989 shown in Table 1, these results are from samples taken from all tillage and cropping system plots. The SOC concentrations were significantly affected by tillage treatment at both the 0- to 7.5- and 15- to 30-cm depths and by the cropping system at all three depths (Table 2). Bulk density values were significantly affected by the tillage system at the 7.5- to 15-cm depth and by the cropping system at the 0- to 7.5- and 15- to 30-cm depths (Table 2). A significant tillage treatment × cropping season interaction was obtained only for SOC concentrations in the 0- to 7.5-cm depth (Table 2).

Our results were similar to those reported by West and Post (2002) in their review of 67 long-term experiments from around the world, where the tillage treatments with the least amount of disturbance had greater SOC concentrations and those with greater disturbance had lower SOC concentrations (Table 2). The lack of significant differences in bulk density values among tillage treatments except at the 7.5- to 15-cm depth was somewhat surprising, but was probably reflective of when the samples were collected. The samples were collected in the fall after harvest

Table 2. Soil organic C concentrations and bulk density values as affected by tillage treatment and cropping system in the 0- to 7.5-, 7.5- to 15-, and 15- to 30-cm depths in 2004 at the Rogers Memorial Farm near Lincoln, NE.

Tillage	Cropping system†	Soil organic C			Bulk density		
		0–7.5 cm	7.5–15 cm	15–30 cm	0–7.5 cm	7.5–15 cm	15–30 cm
		g C kg^{-1}			Mg m^{-3}		
Chisel	CC	19.2	17.2	13.5	1.20	1.39	1.39
	SB-C	18.0	16.0	12.0	1.26	1.36	1.43
	CSB	16.3	14.7	10.8	1.30	1.40	1.47
Disk	CC	20.5	17.0	14.4	1.24	1.44	1.44
	SB-C	18.9	17.0	13.8	1.23	1.43	1.43
	CSB	17.5	16.2	13.3	1.27	1.45	1.45
Plow	CC	16.4	16.6	14.1	1.22	1.38	1.44
	SB-C	15.8	15.8	13.0	1.30	1.39	1.49
	CSB	15.0	15.0	12.7	1.30	1.37	1.47
No-till	CC	23.9	17.2	15.2	1.25	1.44	1.45
	SB-C	21.3	16.5	15.1	1.28	1.44	1.47
	CSB	19.2	15.6	13.6	1.28	1.45	1.47
Ridge-till	CC	20.1	16.4	14.3	1.25	1.43	1.44
	SB-C	19.5	16.5	14.4	1.28	1.43	1.42
	CSB	17.6	15.5	13.4	1.29	1.43	1.47
Subtill	CC	18.9	17.0	15.1	1.17	1.38	1.39
	SB-C	18.2	16.1	13.5	1.25	1.43	1.44
	CSB	16.1	14.8	12.7	1.26	1.43	1.44
CV, %		4.8	5.2	8.0	4.7	3.5	3.5
Source of variation	df	Mean squares					
Replication	5	28.1***	20.9***	74.9***	0.042***	0.027***	0.157***
Tillage (T)	5	64.7***	2.2	13.7**	0.007	0.013*	0.006
Error (*a*)	25	2.1	1.9	3.3	0.007	0.005	0.008
Cropping system (CS)	2	75.4***	23.5***	25.9***	0.036***	0.001	0.011*
T × CS	10	1.9*	0.8	1.2	0.003	0.001	0.002
Error (*b*)	60	0.8	0.7	1.2	0.004	0.002	0.002

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† CC, continuous corn; SB-C, soybean–corn; CSB, continuous soybean.

and before any tillage operations were done, thereby allowing the soils to settle or reconsolidate to similar bulk density values after tillage operations in the spring and summer. As shown in Table 2, the soil bulk density values were similar among tillage treatments. That is, bulk density ranged from 1.17 to 1.30 Mg m^{-3} at the 0- to 7.5-cm depth, 1.36 to 1.45 Mg m^{-3} at the 7.5- to 15-cm depth, and 1.39 to 1.49 Mg m^{-3} at the 15- to 30-cm depth across all tillage treatments.

Significant differences in SOC concentrations among the cropping systems in this study (Table 2) are similar to the results reported by Varvel (1994, 2006), and Varvel and Wilhelm (2008) in other long-term studies in the same geographical area of the United States. In general, soil C concentrations were greatest in the CC cropping system and least in the CSB cropping system, with SB-C values intermediate in all tillage treatments at all three depths (Table 2). These results were very similar to those reported by Varvel and Wilhelm (2008) for the same three cropping systems in an irrigated long-term study in central Nebraska. In that study, all cropping system treatments were tilled with a tandem disk similar to the tandem disk treatment in this study.

The reasons for the significant interaction effect of tillage treatment × cropping system on soil C concentrations in the surface 0- to 7.5-cm depth are not readily apparent when the values in Table 2 are examined. It appears that in all cases, soil C concentration rankings for all tillage treatments were CC > SB-C > CSB. In each of the tillage treatments, soil C concentrations differed in magnitude, so it may be conjectured that the significant interaction was due to the fact that perhaps the relative difference among cropping systems was greater in some tillage treatments than it was in others, for example between plow and no-till treatments (Table 2). In any case, these differences, while significant, appear to be fairly small.

Significant differences in bulk density values were also obtained in the 0- to 7.5- and 15- to 30-cm depths among cropping systems (Table 2). These significant differences at both depths were due to lower bulk density values in the CC cropping system vs. those in the CSB and SB-C cropping systems, 1.22 vs. 1.28 and 1.27 g cm^{-3} (0–7.5-cm depth) and 1.43 vs. 1.46 and 1.45 g cm^{-3} (15–30-cm depth), respectively. Again, these differences, even though significant, were quite small.

The reserves of SOC from the 2004 sampling are shown in Table 3. Utilizing the soil C concentrations and bulk density values shown in Table 2 along with the depth of sampling, the SOC reserves for each of the tillage treatment and cropping system combinations were calculated for each of the three sampled depths. These values were summed to also obtain the SOC reserves for each of the tillage treatment and cropping systems in the 0- to 15- and 0- to 30-cm depths.

Tillage treatment and cropping system significantly affected the SOC reserves in all three individual sampling depths as well as in the cumulative 0- to 15- and 0- to 30-cm depths (Table 3). In all tillage treatments at all depths, the SOC reserves were greatest under no-till and least under plow, with intermediate values under the other tillage treatments (Table 3). Similarly, for cropping systems, SOC reserves ranked CC > SB-C > CSB (Table 3). There was also a significant two-way interaction between tillage treatment and cropping system with respect to SOC reserves in the surface 0- to 7.5-cm depth (Table 3).

Table 3. Soil organic C reserves as affected by tillage treatment and cropping systems in the 0- to 7.5-, 7.5- to 15-, 15- to 30-, 0- to 15-, and 0- to 30-cm depths in 2004 at the Rogers Memorial Farm near Lincoln, NE.

Tillage	Cropping system†	Soil organic C reserves				
		0–7.5 cm	7.5–15 cm	15–30 cm	0–15 cm	0–30 cm
		Mg C ha^{-1}				
Chisel	CC	17.5	18.2	28.4	35.7	64.1
	SB-C	17.2	16.6	25.8	33.8	59.6
	CSB	16.0	15.6	24.0	31.6	55.7
Disk	CC	19.3	18.6	31.4	37.9	69.2
	SB-C	17.6	18.4	30.0	36.0	65.9
	CSB	16.9	17.9	29.1	34.8	63.9
Plow	CC	15.1	17.5	30.7	32.6	63.3
	SB-C	15.6	16.8	29.1	32.4	61.5
	CSB	14.8	15.6	28.3	30.4	58.7
No-till	CC	22.7	18.9	33.7	41.6	75.3
	SB-C	20.8	18.0	33.8	38.8	72.7
	CSB	18.8	17.2	30.2	36.0	66.2
Ridge-till	CC	19.1	17.8	31.2	36.9	68.1
	SB-C	18.9	17.9	31.1	36.8	67.8
	CSB	17.3	16.9	29.7	34.2	63.9
Subtill	CC	16.8	17.8	31.5	34.6	66.0
	SB-C	17.2	17.4	29.5	34.6	64.1
	CSB	15.5	16.0	27.6	31.5	59.1
CV, %		6.4	6.6	7.9	5.5	6.2
Source of variation	df	Mean squares				
Replication	5	24.0***	20.4***	286.5***	87.3***	664.5***
Tillage (T)	5	65.9***	8.1*	81.4**	110.1***	324.6***
Error (*a*)	25	3.7	2.7	18.5	11.5	50.0
Cropping system (CS)	2	33.7***	22.6***	80.5***	111.3***	380.5***
T × CS	10	2.8*	0.9	3.4	3.3	8.6
Error (*b*)	60	1.3	1.3	5.6	3.7	16.1

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† CC, continuous corn; SB-C, soybean–corn; CSB, continuous soybean.

The significant interaction between tillage treatment and cropping system on the SOC reserves in the surface 0- to 7.5-cm depth is demonstrated in Fig. 1. It appears that the significant interaction between tillage treatment and cropping system was obtained because the SOC reserves for the three cropping systems ranked CC > SB-C > CSB in all tillage treatments except for the plow treatment (Fig. 1). These results represent the more uniform mixing that occurs in the surface soil with a plow tillage treatment; also, ridge-till and subtill CC and SB-C systems were similar but greater than the CSB system.

The results from Fig. 1 were different than those obtained for SOC reserves in all the other depth increments including those for the cumulative amounts of SOC reserves (Table 3). Tillage treatment and cropping system main effects were both significant for SOC reserves in each of these depth increments (as noted above), but the tillage treatment × cropping system interaction was not

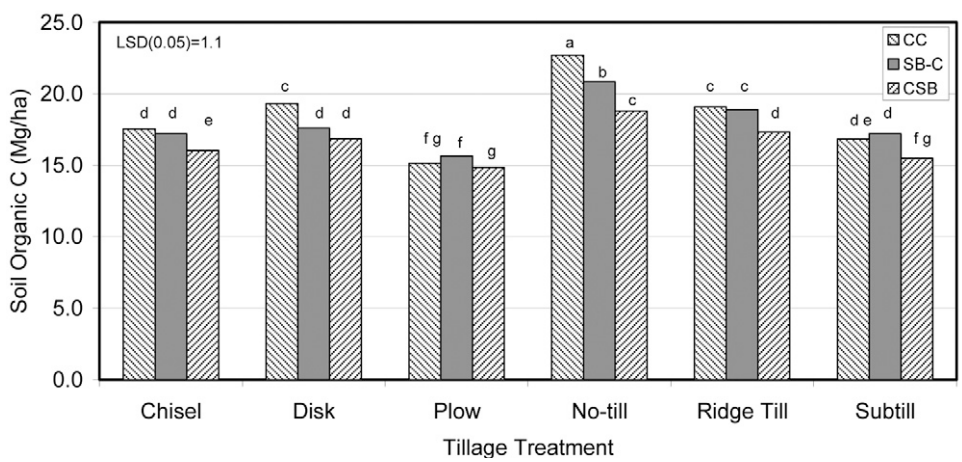

Fig. 1. Soil organic C reserves in the surface 0- to 7.5-cm depth for each cropping system in each of the six tillage treatments in samples collected in the fall of 2004 after harvest at the Rogers Memorial Farm near Lincoln, NE. The LSDs for tillage treatment × cropping system interactions are presented above the bars; bars having different letters are significantly different from each other ($P < 0.05$); CC = continuous corn, SB-C = soybean–corn, CSB = continuous soybean.

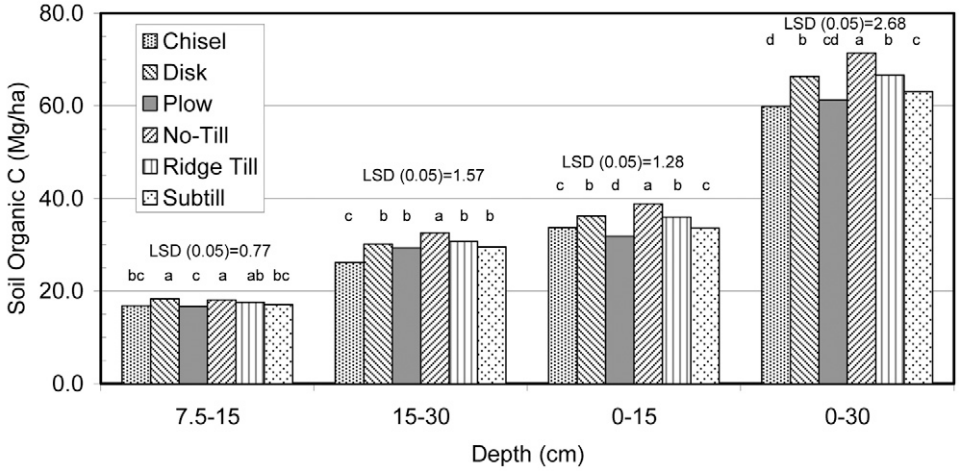

Fig. 2. Soil organic C reserves in the 7.5- to 15-, 15- to 30-, 0- to 15-, and 0- to 30-cm depths for each tillage treatment in the fall of 2004 after harvest at the Rogers Memorial Farm near Lincoln, NE. The LSDs for tillage treatments at each depth are presented above the bars; bars having different letters are significantly different from each other (*P* < 0.05).

(Table 3). Comparisons of SOC reserves among tillage treatments in each of these depth increments are shown in Fig. 2. In all of these depth increments, SOC reserves were generally greatest under no-till and less under the other tillage treatments (Fig. 2). Likewise, comparisons of SOC reserves among cropping systems in each of these depth increments are shown in Fig. 3. In all of these same depth increments, SOC reserves ranked CC > SB-C > CSB (Fig. 3). The data presented in these two figures demonstrate that when you examine SOC reserves among tillage treatments and cropping systems throughout the entire 0- to 30-cm sampling depth (Fig. 2 and 3), changes in SOC reserves were very consistent among the cropping systems, regardless of tillage treatment. These results, especially those for the 0- to 15- and 0- to 30-cm depths, appear to be more representative of changes in SOC reserves that have occurred, because these depths encompass most of the range in depths of tillage for these tillage treatments (Fig. 2 and 3).

In an attempt to address the changes in SOC with time, we compared soil C concentrations from the same plots in 2004 to those sampled in 1989 (Table 4). These results were compared with the assumption that similar depths were sampled in both years from the five tillage treatments following corn only in the CC and SB-C cropping systems in the first three replications that were sampled in 1989, which may be incorrect because bulk density values were not taken in 1989. Also, soil C concentrations were determined using different methods in 1989 and 2004; the absolute C concentrations obtained in 1989 by making the conversion calculation from organic matter content may be different if another conversion percentage is used. This assumption may affect the actual magnitude of the soil C concentrations in 1989, but because any conversion factor would be a constant, the relative relationship from 1989 to 2004 would still exist. Nevertheless, when using this approach and the conversion factor from Combs and Nathan (1998), our estimated 1989 to 2004 changes in SOC concentrations in these plots were significantly increased only in the near-surface 0- to 7.5-cm depth (Table 4). A similar trend does appear to be present for changes in SOC concentrations at the other two depths, but given the variability in the data, as can be seen when their CVs are examined, those changes were not statistically significant (Table 4). Examination of the SOC changes in all five of the tillage systems appears to indicate that only in the plow tillage treatment have soil C concentrations remained relatively unchanged during this 15-yr period (Table 4). The use of a different conversion factor, as mentioned above, could alter the actual magnitude of the changes shown in Table 4, but the relationship at each depth would remain the same.

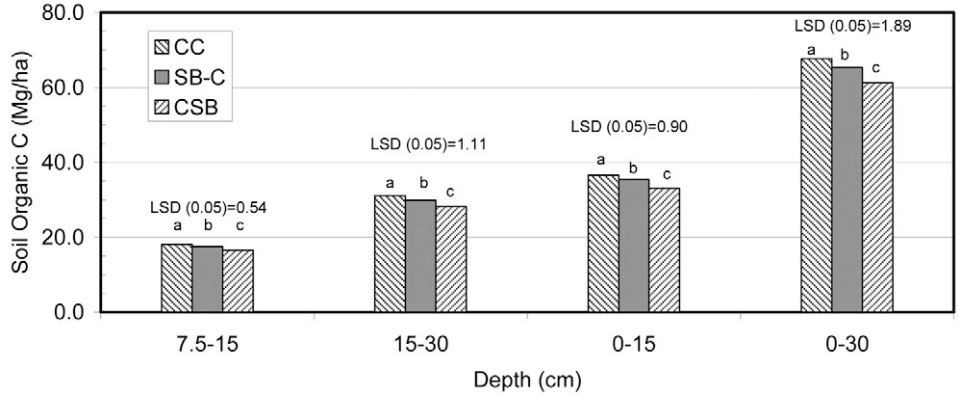

Fig. 3. Soil organic C reserves in the 7.5- to 15-, 15- to 30-, 0- to 15-, and 0- to 30-cm depths for each cropping system in the fall of 2004 after harvest at the Rogers Memorial Farm near Lincoln, NE. The LSDs for cropping systems at each depth are presented above the bars; bars having different letters are significantly different from each other (*P* < 0.05); CC = continuous corn, SB-C = soybean–corn, CSB = continuous soybean.

SUMMARY

Unfortunately, soil samples taken at the beginning of this long-term study were not archived nor were they analyzed for organic matter or soil C; however, the results from samples that were taken from selected treatments and replications, as reported above, give us an approximation of soil C status in 1989. These results provide some basic information regarding soil C concentrations from the first three replications following corn in the CC and SB-C cropping systems in five of six tillage treatments 9 yr after tillage treatments and 4 yr after cropping

systems were initiated. At this point, no significant differences in soil C concentrations were obtained from soil samples taken from the first three replications (Table 1).

In contrast, soil samples collected from every tillage treatment and cropping system plot in 2004 demonstrated significant differences in soil C concentrations due to both tillage treatment and cropping system at most of the sampling depths (Table 2) and SOC reserves at all depths (Table 3). It appears that SOC reserves were generally greatest in the no-till treatment, with values in the other tillage treatments somewhat less (Fig. 2). As demonstrated in Fig. 3, all three cropping systems affected SOC reserves in each tillage treatment similarly.

These results suggest that SOC values have generally increased in all cropping systems in five of the six tillage treatments to a depth of 30 cm in this long-term study, a result that supports the hypotheses of West and Post (2002). A comparison of the changes in SOC concentrations from 1989 to 2004 in a limited number of the plots in this study also supports this conclusion (Table 4). More importantly, these results indicate that soil C levels can be maintained or even increased in these types of cropping systems when some form of reduced or conservation tillage is used in this or similar environments throughout the western Corn Belt.

Table 4. Change in soil organic C (ΔSOC) concentrations from 1989 to 2004 in the 0- to 7.5-, 7.5- to 15-, and 15- to 30-cm depths as affected by five tillage treatments in plots in the first three replications planted to corn at the Rogers Memorial Farm near Lincoln, NE.

Tillage		ΔSOC (1989–2004)		
		0–7.5 cm	7.5–15 cm	15–30 cm
		g C kg^{-1}		
Chisel		2.24	1.24	1.30
Disk		3.38	1.30	1.12
Plow		0.33	0.47	1.43
No-till		4.65	1.83	1.71
Subtill		3.17	1.39	2.91
CV, %		56.7	99.3	108.0
Source of variation	df	Mean squares		
Replication	2	5.99	0.95	7.28
Tillage	4	15.43***	1.45	3.04
Error	23	2.44	1.52	3.34

*** Significant at the 0.001 probability level.

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