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Article *in* Soil and Tillage Research · April 2005

DOI: 10.1016/j.still.2004.09.009

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Soil & Tillage Research 81 (2005) 217–225
Soil & Tillage Research
www.elsevier.com/locate/still

Soil organic carbon changes after 12 years of no-tillage and tillage of Grantsburg soils in southern Illinois

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Abstract

Many factors including management history, soil type, climate, and soil landscape processes affect the dynamics of soil organic carbon (SOC). The primary objective of this research was to determine the effects of no-tillage and tillage systems on the SOC content after 12 years of controlled treatments. A tillage experiment with three treatments (no-till (NT), chisel plow (CP) and moldboard plow (MP)) was initiated in the spring of 1989 in southern Illinois. The plot area was previously in a tall fescue hayland for 15 years and had a 6% slope. Maize (*Zea mays* L.) and soybean (*Glycine max* L. Merr.) were grown in the plot area on a yearly rotation system starting with maize. Periodically, the SOC content of various soil layers, to a depth of either 30 or 75 cm, was measured and expressed on both a gravimetric and volumetric basis. After 12 years, the 0–15 cm surface soil layer of MP was significantly lower in SOC than the NT and CP plots. For all but 2 values, the significance of findings did not change with the form of expression (gravimetric versus volumetric). The surface layer (0–15 cm), subsoil (15–75 cm), and rooting zone (0–75 cm) of all treatments had reduction in SOC on a volumetric basis when compared to the pre-treatment values for sod. At the end of the 12-year study, the MP system had significantly less SOC in the surface layer, subsurface layer and rooting zone than the NT system at comparable depths. After 12 years of tillage under a maize–soybean rotation, the NT treatment sequestered or maintained more SOC stock (47.0 Mt ha^{-1}) than the CP (43.7 Mt ha^{-1}) and MP (37.7 Mt ha^{-1}) treatments. The annual rate of SOC stock build up in the root zone (0–75 cm), above the MP system base, was 0.71 Mt ha^{-1} $year^{-1}$ for the NT system and 0.46 Mt ha^{-1} $year^{-1}$ for the CP system. For land coming out of the Conservation Reserve Program and returning to row crop production, NT and CP systems would maintain more SOC stock than MP system and reduce CO_2 emissions to the atmosphere.

Keywords: Organic carbon; Soil erosion; Soil loss; Tillage; No-tillage

1. Introduction

1.1. Tillage effects on SOC

Gregorich et al. (1998) found most soils undergo about a 20% to 30% loss of soil organic carbon (SOC)

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0167-1987/$ – see front matter
doi:10.1016/j.still.2004.09.009

by mineralization when they are brought under arable agriculture. In addition, even greater losses and gains of SOC may occur as a result of erosion and deposition. Odell et al. (1984) summarized the SOC data for the Morrow Plots from 1904 to 1973. Compared with continuous sod plots, this represented a 42% loss of SOC in 69 years, with most of the change happening in the first 28 years.

There is evidence that reduction in tillage and NT can result in sequestration of C (Lal et al., 1994; Campbell et al., 1995). Angers et al. (1997) measured difference in NT, CP and conventional tillage (CT) for 11 years in eastern Canada and concluded that most soils under reduced tillage had more SOC in the top 10 cm than under CT but this was offset by less SOC at lower depths.

VandenBygaart (2001) suggested past erosion and deposition have resulted in redistribution of SOC in the landscape and have yet to be considered effectively in the study of SOC dynamics and the potential for C sequestration in agricultural soils. Janzen et al. (1998) monitored the change in SOC over time in agricultural soils and found soil management to be key to understanding sequestration of C from atmosphere. VandenBygaart et al. (2002) measured the changes in SOC under 15 years of NT in southern Ontario and found when the entire soil column was considered there was a loss of SOC in more profiles than there were gains. VandenBygaart et al. (2002) found many other factors including climate, management history, soil type and soil landscape process affected the dynamics of SOC under NT.

In North Dakota, Halvorson et al. (2002) estimated 233 kg C ha^{-1} $year^{-1}$ of SOC was sequestered with an annual cropping system under NT when compared with 25 kg C ha^{-1} with minimum tillage (MT) and a loss of 141 kg C ha^{-1} with CT. Using NT farms in Ohio, Shukla and Lal (2004) found SOC stocks increased from a base value at a rate of 0.58 Mg ha^{-1} $year^{-1}$ for the 0–10 cm, 0.28 Mg ha^{-1} $year^{-1}$ for the 10–20 cm layer and a combined increase of 0.86 Mg ha^{-1} $year^{-1}$ for the upper 0–20 cm of Miamian soils.

1.2. SOC distributions

Change in frequency and intensity of tillage practices alter the bulk density and SOC in the soil profile. The SOC results have been reported on either a gravimetric or volumetric basis. Mann (1986) reported that the reduction in volumetric SOC of soils having an initial content of 2–5% (absolute) was 20% less after cultivation. He found changes in SOC content were most pronounced during the first 20 years of cultivation. Also, changes in SOC storage were more variable in the upper 15 cm of soil than in the upper 30 cm. Kitur et al. (1994) and Hussain et al. (1999) evaluated the effects of moldboard plow (MP), chisel plow (CP) and no-till (NT) on gravimetric SOC content of the surface layers and found the content was lowest for MP and highest for NT. The treatment differences in SOC were attributed to the effects of plant residue incorporation below the 0–5 cm layer in the MP and CP treatments. Effects of tillage on SOC content were not significant in the 5–15 cm layer. Ismail et al. (1994) observed a decrease in volumetric SOC in the 0–30 cm silt loam layer during the first 5 years, no change in the next 5 years, and an increase in SOC in the last 10 years in both NT and MP in comparison with sod plots. The SOC was higher in NT than in MP. Hunt et al. (1996), Alvarez et al. (1995), and Angers and Giroux (1996) found NT systems increased gravimetric SOC content, compared with MP and CP systems, in the top 5 cm layer of soils with a range of soil textures, including loamy sand, silt loam, and silty clay loam. Karlen et al. (1994) found an increase in volumetric SOC content under NT, compared with MP and CP, in the top 5 cm of loamy sand, silt loam, and silty clay loam soils.

1.3. Soil erosion and carbon dynamics

The SOC dynamics are affected by tillage, no-tillage, soil erosion and depositional processes. The SOC within the topsoil can easily be transported, especially on sloping sites, by tillage translocation and subsequent transport by water and wind action. The SOC stock of a soil can be affected by specific tillage practices. Tillage can expose the soil organic matter to the oxidation processes that result in SOC removal as CO_2, to more rapid decomposition of crop residues into CO_2, and to disruption of aggregates that exposes SOC to microbial and enzyme activity. Tillage may accelerate leaching of soluble SOC and inorganic carbonate. Tillage on sloping soils can further reduce SOC by tillage translocation and erosion of soil material rich in SOC by water and wind action whereby there is subsequent deposition. The primary objectives of this research were: (1) to determine the effects of 12 years of no-tillage and tillage systems on SOC content of the surface layer, subsoil, and root zone; and (2) to determine if the expression of SOC on a volumetric basis rather than a gravimetric basis would affect the significance of the results.

2. Materials and methods

2.1. Field experiment

A tillage experiment with three treatments no-tillage (NT), chisel plow (CP) and moldboard plow (MP) was initiated in the spring of 1989 in southern Illinois on a Grantsburg soil (Albic Luvisol) (fine-silty, mixed, active, mesic Oxyaquic Fragiudalf). The plot area soil had a root restricting fragipan at 75 ± 5 cm. A representative description of the Grantsburg soil profile is provided in Table 1. The plot area was previously in a tall fescue (*Festuca arundinacea* L.) abandon hayland for at least the previous 15 years and had a 6% slope. The experimental design was a complete latin square with two squares and each square had three rows and three columns. Three tillage treatments were randomized six times in 18 plots with each plot being 9 m × 12 m in size. The implements used in each tillage system and depth of tillage were as follows: NT (John Deere No-till planter with wavy coulters), CP (straight-shanked chisel plowed to 15 cm with diskings to 5 cm), and MP (moldboard plowed to 17 cm with diskings to 5 cm). Maize and soybeans were grown on the plot area on a yearly rotation system starting with maize. In odd years, maize was planted at the seeding rate of 64,000 seeds ha^{-1} on the same date for all treatments with fertilizers rates of 218 kg ha^{-1} N, 55 ha^{-1} P, and 232 kg ha^{-1} K. In even years, soybeans were planted on the same date at 432,000 seeds ha^{-1} on all treatments with no fertilizer. Chemical weed control practices were used during the study.

2.2. Field and laboratory methods

Soil samples were collected during fall of 1988 from the sod prior to the application of tillage treatments and mid-season in years 1989, 1990, 1991, 1992, 1995, 1996, and 2000, at depths of 0–5-, 5–15, and 15–30 cm for SOC determination. During 1988, 1989, and 2000 additional depths of 30–45, 45–60, and 60–75 cm were included for analysis. Four soil cores, one each from near the four corners of each plot (1.5 m from adjacent, above or below plot, and 1.5 m from border strip), were obtained and composited by depth. The sampling depths were grouped into surface layer (0–15 cm), subsoil layer (15–75 cm) and rooting zone (0–75 cm) for data comparison purposes. The samples were air-dried and pulverized to pass a 2 mm sieve prior to textural analysis for sand, silt and clay contents (Soil Survey Staff, 1984). After removal of un-decomposed plant residue, SOC was determined using the Walkley–Black procedure (Soil Survey Staff, 1984). Field moist core bulk density was determined (Soil Survey Staff, 1984) using a Model 2000 soil core sampler manufactured by Soil Moisture Equipment Corp (Goleta, California).

2.3. Statistical methods

Statistical analyses were preformed using Statistical Analysis System (SAS) computer software (SAS Institute Inc., 1995). An LSD procedure was used at the $P = 0.05$ level to determine if there were significant SOC differences between tillage treatments for the same date and depth and for differences between pre-treatment values for abandon sod and after 12 years of tillage treatments.

Table 1
Description of representative Grantsburg pedon at cultivated site

Horizon	Depth (cm)	Matrix color	Gray mottles	Texture	Clay (%)
Ap	0–17	10YR4/3	–	Silt loam	17
Bt1	17–37	10YR5/4	–	Silty clay loam	28
Bt2	37–52	10YR5/4	10YR6/2	Silty clay loam	28
Bt/E	52–64	10YR5/6	10YR6/2	Silt loam	21
Btx	64–120+	7.5YR5/4	7.5YR6/2	Silt loam	19

3. Results and discussion

The SOC contents of the Grantsburg soil of the tillage plots are provided in Table 2. There were no significant differences in mean SOC levels for any soil layer for the plots under sod (year 1988) prior to establishment of tillage treatments. Apparently, the proposed plot design with six replications was sufficient to minimize the natural SOC variability between proposed treatment locations (Table 2, column 2). Significant difference between MP and CP for the 0–5 cm layer were noted in the years 1990, 1991, 1996 and 2000. From 1989 through 2000 the SOC content in 0–5 cm layer of the MP system was significantly lower than the NT system. The NT values for SOC in the 0–5 cm layer were similar to the CP values for all years except 1990, 1991, and 1996. For the 5–15 cm layer, the MP treatment had significantly lower SOC content after 12 years than the NT and CP treatments. Temporary differences between treatments in SOC content in the 0–5 cm and 5–15 cm layers were attributed to the effects of incorporated plant residue in MP and CP systems. Subsoil values of SOC for NT were significantly higher than CP for the 30–45 cm layer and NT was significantly higher than MP for the 30–45 cm and 45–75 cm layers after 12 years (Table 2). After 12 years, the surface layer (0–15 cm) and the root zone (0–75 cm) of the NT and CP were found to be significantly higher in SOC content than the MP treatment.

The bulk density data by treatment are provided in Table 3 for all the depths and sample years. As expected the NT treatment had the highest bulk densities in mid-season but the values were not significantly different from either MP or CP. The 0–15 cm layers of the CP and MP soil treatment had sufficient time between tillage and sampling for re-consolidation to occur. The bulk density (Table 3) was used to convert the SOC content from a gravimetric basis to volumetric basis.

The NT treatment relative to sod maintained the volumetric SOC content in the 0–5 cm layer (Table 4) through the 12 years of the study. The SOC content of NT of 0–5 cm layer was significantly higher than MP

Table 2
Effects of 12 years of tillage on the gravimetric SOC content (g kg^{-1}) of the Grantsburg soil previously in abandon sod

Treatment	Depth (cm)	September 1988	July 1989	August 1990	July 1991	August 1992	July 1995	August 1996	August 2000
NT	0–5	17.3 a	17.5 a	18.0 a	17.9 a	16.5 a	16.9 a	17.5 a	17.4 a
	5–15	12.4 a	11.8 a	12.1 a	11.5 a	11.3 b#	11.3 a	11.8 a	10.6 a
	15–30	6.4 a	3.7 a	4.3 a	4.2 a	4.7 a	4.4 a	3.7 a	4.6 a
	30–45	2.4 a	2.5 a						2.2 a
	45–60	1.2 a	1.3 a						1.5 a
	60–75	1.3 a	1.2 a						1.2 a
	0–75 (combined)	5.1 a	4.5 a						4.5 a
CP	0–5	17.1 a	15.3 b	15.6 b	15.4 b	15.2 ab	15.4 ab	15.3b	16.2 a
	5–15	12.4 a	11.9 a	9.4 b	11.3 a	12.6 a	11.1 a	11.9a	10.9 a
	15–30	6.3 a	3.7 a	3.9 ab	3.4 b	4.3 a	4.0 a	4.5b	4.6 a
	30–45	2.3 a	2.5 a						1.5 b
	45–60	1.2 a	1.3 a						1.8 a
	60–75	1.3 a	1.2 a						0.9 ab
	0–75 (combined)	5.0 a	4.3 a						4.3 a
MP	0–5	16.8 a	15.3 b	11.5 c	12.1 c	12.8 b	11.5 b	10.8c	11.6 b
	5–15	12.6 a	12.3 a	10.6 ab	11.4 a	11.2 b	10.9 a	12.3 a	9.4 b
	15–30	6.1 a	4.5 a	3.4 b	4.3 a	4.6 a	4.4 a	4.5 b	4.4 a
	30–45	2.2 a	2.3 a						2.1 a
	45–60	1.2 a	1.4 a						1.2 b
	60–75	1.3 a	1.3 a						0.7 b
	0–75 (combined)	5.0 a	4.6 a						3.7 b

Mean of six replications with the same letter in different treatments for the same depth and year are not significantly different at $P = 0.05$. Findings differ from those in Table 4, which were expressed on a volumetric basis.

Table 3
Effects of abandon sod and tillage on the bulk density (g cm^{-3}) (core method) of the Grantsburg soil from 1988 to 1996 with estimate for 2000

Treatment	Depth (cm)	September 1988	July 1989	August 1990	July 1991	August 1992	July 1995	August 1996	August 2000
NT	0–5	1.35 a	1.37 a	1.42 a	1.37 a	1.40 a	1.37 a	1.40 a	1.39 a
	5–15	1.35 a	1.37 a	1.42 a	1.37 a	1.40 a	1.37 a	1.40 a	1.39 a
	15–30	1.40 a	1.40 a	1.40 a	1.40 a	1.40 a	1.40 a	1.40 a	1.40 a
	30–45	1.40 a	1.40 a						1.40 a
	45–60	1.45 a	1.45 a						1.45 a
	60–75	1.45 a	1.45 a						1.45 a
CP	0–5	1.35 a	1.42 a	1.36 a	1.26 a	1.26 a	1.36 a	1.26 a	1.32 a
	5–15	1.35 a	1.42 a	1.36 a	1.26 a	1.26 a	1.36 a	1.26 a	1.32 a
	15–30	1.40 a	1.40 a	1.40 a	1.40 a	1.40 a	1.40 a	1.40 a	1.40 a
	30–45	1.40 a	1.40 a						1.40 a
	45–60	1.45 a	1.45 a						1.45 a
	60–75	1.45 a	1.45 a						1.45 a
MP	0–5	1.35 a	1.36 a	1.38 a	1.25 a	1.27 a	1.31 a	1.25 a	1.31 a
	5–15	1.35 a	1.36 a	1.38 a	1.25 a	1.27 a	1.31 a	1.25 a	1.31 a
	15–30	1.40 a	1.40 a	1.40 a	1.40 a	1.40 a	1.40 a	1.40 a	1.40 a
	30–45	1.40 a	1.40 a						1.40 a
	45–60	1.45 a	1.45 a						1.45 a
	60–75	1.45 a	1.45 a						1.45 a

Estimate from the mean of previous years. Mean with the same letter in different treatments for the same depth and year are not significantly different at $P = 0.05$.

Table 4
Effects of 12 years of tillage on the volumetric SOC content (kg $layer^{-1}$ (thickness × 1 m × 1 m volume)) of the Grantsburg soil

Treatment	Depth (cm)	September 1988	July 1989	August 1990	July 1991	August 1992	July 1995	August 1996	August 2000
NT	0–5	1.17 a	1.20 a	1.28 a	1.23 a	1.16 a	1.14 a	1.23 a	1.21 a
	5–15	1.68 a	1.62 a	1.71 a	1.57 a	1.58 a	1.54 a	1.65 a	1.47 a
	15–30	1.33 a	0.78 a	0.90 a	0.88 a	0.99 a	0.92 a	0.78 a	0.97 a
	30–45	0.49 a	0.52 a						0.46 a
	45–60	0.26 a	0.28 a						0.33 a
	60–75	0.28 a	0.26 a						0.26 a
	0–75 (combined)	5.21 a	4.66 a						4.70 a
CP	0–5	1.16 a	1.09 ab	1.06 b	0.97 b	0.96 ab	1.05 ab	0.96 b	1.07 a
	5–15	1.68 a	1.69 a	1.27 b	1.42 a	1.59 a	1.52 a	1.50 a	1.43 a
	15–30	1.32 a	0.95 a	0.82 ab	0.71 b	0.90 a	0.84 a	0.95 b	0.96 a
	30–45	0.46 a	0.48 a						0.32 b
	45–60	0.27 a	0.30 a						0.39 a
	60–75	0.28 a	0.28 a						0.20 ab
	0–75 (combined)	5.19 a	4.79 a						4.37 a
MP	0–5	1.13 a	1.03 b	0.79 c	0.76 c	0.81 b	0.75 b	0.68 c	0.76 b
	5–15	1.70 a	1.67 a	1.46 ab	1.42 a	1.42 b	1.43 a	1.54 a	1.23 b
	15–30	1.30 a	0.94 a	0.71 b	0.90 a	0.97 a	0.92 a	0.95 b	0.92 a
	30–45	0.47 a	0.50 a						0.45 a
	45–60	0.26 a	0.26 a						0.26 b
	60–75	0.28 a	0.28 a						0.15 b
	0–75 (combined)	5.14 a	4.78 a						3.77 b

Mean of six replications with the same letter in different treatments for the same depth and year are not significantly different at $P = 0.05$. Findings differ from those in Table 2, which were expressed on a gravimetric basis.

Table 5
Effects of 12 years of tillage systems on the volumetric SOC (Mt ha^{-1} layer^{-1} (thickness × 100 m × 100 m)) content of the Grantsburg soil

Treatment	Depth (cm)	Pre-treatment sod in September 1988 (Mt ha^{-1} layer^{-1})	Treatments applied through August 2000 (Mt ha^{-1} layer^{-1})	Loss of SOC in 12 years (Mt ha^{-1} layer^{-1})	Loss of SOC in 12 years (decrease %)	Loss of SOC stock from sod (Mt ha^{-1} layer^{-1} year^{-1})	Build up of SOC stock from MP (Mt ha^{-1} year^{-1})	Build up of SOC stock above MP (Mt ha^{-1} layer^{-1} year^{-1})
NT	0–15	28.5 a	26.8 a	1.7	6	0.14	6.9	0.55
	15–75	23.6 a	20.2 a	3.4	14	0.28	2.4	0.16
	0–75 combined	52.1 a	47.0 a	5.1	10	0.42	9.3	0.71
CP	0–15	28.4 a	25.0 a	3.4	12	0.28	5.1	0.43
	15–75	23.5 a	18.7 ab	4.8	20	0.40	0.9	0.03
	0–75 combined	51.9 a	43.7 a	8.2	16	0.68	6.0	0.46
MP	0–15	28.3 a	19.9 b	8.3	29	0.70	–	–
	15–75	23.1 a	17.8 b	5.3	23	0.44	–	–
	0–75 combined	51.4 a	37.7 b	13.7	27	1.14	–	–

Mean of six replications with the same letter in same treatments and thickness and different years are not significantly different at $P = 0.05$.

from 1989 through 2000. The CP treatment was also significantly higher than MP in years 1990, 1991, 1996, and 2000 (Table 4). In the 5–15 cm layer the MP treatment had a significantly lower SOC content after 12 years than both the CP and NT systems. Subsoil values for NT were significantly higher than CP for the 30–45 cm layer and NT was significantly higher than MP for the 30–45 cm and 45–75 cm layers after 12 years (Table 4) when expressed on a volume basis.

A comparison of the gravimetric SOC values (Table 2) with volumetric values (Table 4) does show that the significance of the findings may vary with method of expression. For example there was the significant difference in SOC between the NT and CP in the 0–5 cm layer on a gravimetric basis (Table 2) in 1990 was not noted in data expressed on a volumetric basis (Table 4). In 1992, 5–15 cm of CP was significantly lower than the NT when expressed on a volumetric basis (Table 4) but not on a gravimetric basis (Table 2). However, these would be the only two differences that occurred for all the SOC values provided in Tables 2 and 4 and these differences did not occur in any of the following years. This data set would support expressing SOC values on only one basis. We expressed the remaining data on a volumetric basis rather than a gravimetric basis since SOC in soil profile can be more easily expressed on an area basis using the volumetric approach.

The SOC content data by volume was summarized in Table 5 for all treatments for the potential tillage zone (0–15 cm), the subsoil layer (15–75 cm), and the root zone (0–75 cm). The total SOC loss from the root zone of the original sod after 12 years was 5.1 Mt ha^{-1} for NT, 8.2 Mt ha^{-1} for the CP and 13.7 Mt ha^{-1} from MP system. The MP system also showed significant SOC content losses (Table 5) when compared to CP system for the tillage zone and root zone, but no significant differences for the subsoil layer. The differences in SOC between treatments in the tillage zone was attributed to the effects of management on erosion, disturbance, aeration and residue incorporation.

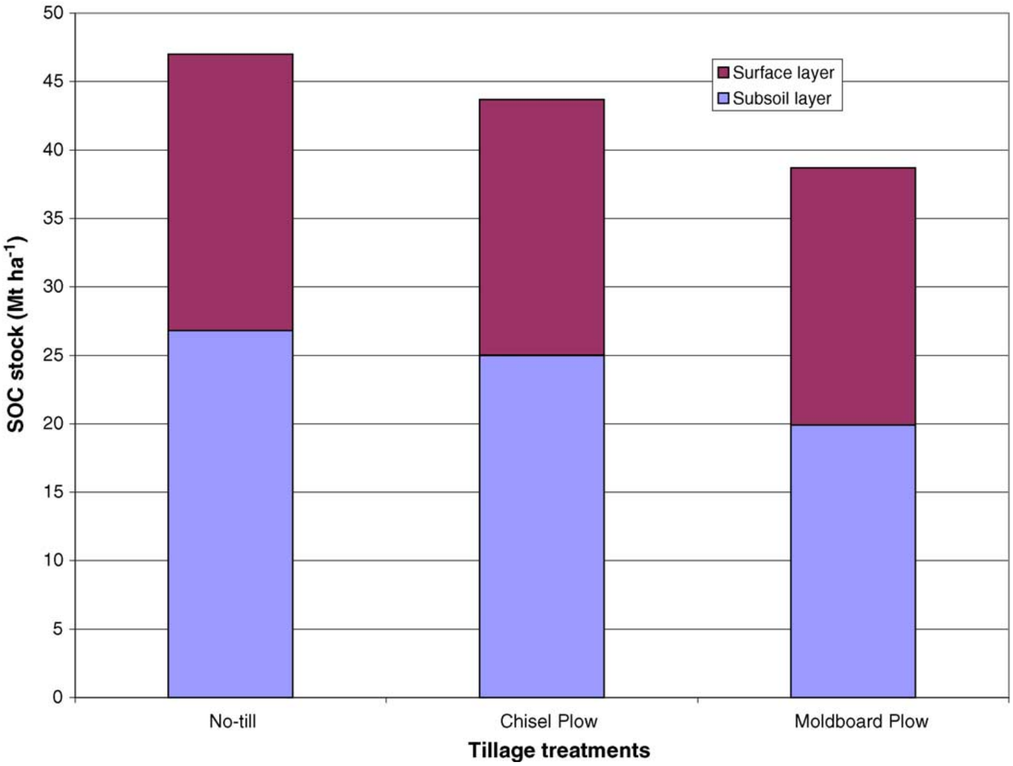

Fig. 1. The soil organic carbon (SOC) stock in the root zone (0–75 cm) of a Grantsburg soil after 12 years of tillage and no-tillage treatments under a maize–soybean rotation.

The SOC levels of the original sod (Table 5) decreased after 12 years under the NT system by 6% in the tillage zone, 14% in the upper undisturbed subsoil and by 10% for the entire root zone. The SOC levels of the original sod decreased under the CP system by 12% in the tilled zone, 20% in the subsoil and by 16% for the root zone. The SOC levels of the original sod decreased under the MP system by 29% in the tilled zone, 23% in subsoil and by 27% for the entire root zone. The SOC means for the tilled zone, subsoil and root zone were analyzed and are reported in Table 5. Significant differences in the SOC level occurred for occurred for the surface, subsoil and rooting zone of the MP treatment when compared to corresponding soil layers of NT. There were non-significant differences in the SOC levels of the surface, subsoil and rooting zone of the NT and CP systems. The CP system had significantly more SOC in the surface layer and root zone than MP system.

After 12 years, the remaining SOC stock in the rooting zone of the NT, CP and MP are shown in Fig. 1. Clearly, the NT and CP systems retain significantly more SOC stock in the surface, subsoil and root zone layers (Table 5, column 4).

After 12 years of tillage under a maize-soybean rotation, the NT treatment sequestered or maintained more SOC stock (47.0 Mt ha^{-1}) than the CP (43.7 Mt ha^{-1}) and MP (37.7 Mt ha^{-1}) treatments (Fig. 1). The annual rate of SOC stock build up in the root zone (0–75 cm), above the MP system base, was 0.71 Mt ha^{-1} $year^{-1}$ for the NT system and 0.46 Mt ha^{-1} $year^{-1}$ for the CP system (Table 5).

4. Conclusions

The NT and CP systems maintained SOC levels better than the MP system in potential tilled zone. The volumetric SOC levels in the potential tillage zone, the subsoil and for the entire root zone decreased after 12 years under the NT, CP, and MP systems when compared with the pre-treatment values for abandon sod. The MP system had significantly lower SOC levels in the tilled zone, the subsoil and the root zone than the NT system. The CP system had significantly more SOC in the surface layer and root zone than MP system. There were no significant differences in the SOC levels of the surface, subsoil and rooting zone of the NT and CP systems. The NT and CP treatments sequestered or maintained more SOC than MP systems.

After 12 years of tillage under a maize-soybean rotation, the NT treatment sequestered or maintained more SOC stock (47.0 Mt ha^{-1}) than the CP (43.7 Mt ha^{-1}) and MP (37.7 Mt ha^{-1}) treatments (Fig. 1). The annual rate of SOC stock build up in the root zone (0–75 cm), above the MP system base, was 0.71 Mt ha^{-1} $year^{-1}$ for the NT system and 0.46 Mt ha^{-1} $year^{-1}$ for the CP system. The difference in SOC between treatments in the tillage zone was attributed to the effects of management on erosion, disturbance, aeration and residue incorporation. For any land returning to row crop production from the Conservation Reserve Program and, NT and CP systems would maintain more SOC than MP systems. The maintenance of SOC with NT and CP systems, compared to MP system, should reduce CO_2 emissions to the atmosphere.

Acknowledgment

Published with the approval of the Director of the Illinois Office of Research, Urbana, IL. Funded as part of Regional Research Project no. 15-367 and in cooperation with North-Central Regional Projects NC-174/NCT-199 (Soil Erosion-Productivity) and NCR-3 (Soil Survey).

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