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On farm assessment of tillage impact on soil carbon and associated soil quality parameters

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ABSTRACT

No-tillage (NT) farming offers innumerable benefits to soil and water conservation, however, its potential to sequester soil organic carbon (SOC) and related soil properties varies widely. Thus, the impact of long-term (>4 yr) NT-based cropping systems on SOC sequestration and selected soil physical and chemical parameters were assessed across soils within five Major land Resource Areas (MLRAs: 99 and 111 in Michigan; 124 and 139 in Ohio; and 127 in Pennsylvania) in eastern U.S.A. Soil samples were collected from paired fields of NT and plow tillage (PT) based cropping systems and an adjacent woodlot (WL). The SOC concentration, bulk density (ρ_b), texture, pH, electrical conductivity (EC), soil N, coarse particulate organic matter (CPOM) C and N, and nitrate N (NO_3-N) concentrations were determined. Conversion from NT to PT practice increased surface soil pH from 5.97, 6.56 and 6.02 to 6.62, 6.91 and 7.09 under MLRAs 127, 111 and 99, respectively. NT soils had higher SOC concentration soils by 30, 50 and 67% over PT soils at 0–5 cm depth under MLRAs 99, 111 and 127, respectively. Considering the whole soil profile SOC, WL had higher SOC pool than NT and PT practices under MLRAs 99, 111 and 124, however, there was no significant difference ($P < 0.05$) between NT and PT practices across five soils. Almost the same trend was observed in the case of depthwise soil N content. NT soil had higher N content than PT soils by 27, 44 and 54% under MLRAs 99, 127 and 111, respectively. However, whole soil profile N content of NT soil was significantly higher by 12% than PT soil under MLRA 99. Concentrations of CPOM associated C and N of NT soil was higher than PT soil under MLRAs 99, 111 and 127 at 0–5 soil depth. These results indicated that impact of tillage on soil C and associated soil quality parameters is confined within specific soil types.

1. Introduction

Globally agricultural lands have the potential to sequester approximately 5500–6000 Mt CO_2-eq. yr^{-1} by 2030 (Smith et al., 2008). Conservation tillage practices can play a leading role in achieving this mitigation potential. Loss of soil organic SOC under conventional tillage have been extensively documented (Lal and Kimble, 1997; West and Post, 2002; Conant et al., 2007). While NT farming is recommended to conserve soil and water and reduce production costs, its potential to sequester SOC varies widely due to complex interactions among climate, soil type, crop rotation, duration and management factors (VandenBygaart et al., 2002; Puget and Lal, 2005).

Long-term (>10 yr) of NT practices have the potential to reduce greenhouse gas emissions in humid climates, but a high degree of uncertainty lies in the case of dry climate regimes (Six et al., 2004). Moreover, increase in SOC sequestration with NT practices depends on soil type. Puget and Lal (2005) reported that increase in SOC concentrations after 8 yr NT management was limited to upper 0–5 cm soil depth in a Mollisol of central Ohio. Most of the previous work evaluated the impact of tillage on SOC concentrations only within the surface soil layers (<30 cm). Deeper sampling (>30 cm) has shown inconsistent results (VandenBygaart et al., 2002; Blanco-Canqui and Lal, 2008). These inconsistencies of NT farming warrant further research to quantify SOC stocks for the whole soil profile in NT.

While there may not be a direct relationship between tillage and soil C sequestration in some soils, NT practices can positively influence soil chemical quality parameters (e.g., aggregation and biological activity) which favor SOC sequestration potential. Based on the data from 36 farmers' fields in Illinois, Wander and Bollero (1999) concluded that increased soil disturbance associated with tillage reduced particulate organic C, and total N and mineralizable N. Also, NT practices improved the biological and physical condition of soils in the surface layers (<15 cm), despite increased consolidation. Blanco-Canqui and Lal (2007) reported that long-tern NT

Abbreviations: MLRA, Major Land Resource Area; NT, no-tillage; PT, plow tillage; WL, woodlot; SOC, soil organic carbon; CPOM, coarse particulate organic matter.

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practices induced moderate changes in soil compaction and aggregate stability. Organic acids formed during the decomposition of crop residues sometimes result in a short-term increase in soil acidity (Ismail et al., 1994). Thus, simultaneous assessment of soil physical, chemical and biological parameters including bulk density, texture, pH, EC, particulate organic matter, and NO_3-N may provide better insights into the mechanisms responsible for soil C sequestration potential under NT technology.

Most of the previous research work on tillage management has been conducted on small plots. This approach has made the interferences of NT management impacts on SOC sequestration and soil quality parameters on a farm scale somewhat difficult. Data from research plots cannot be directly extrapolated to field scale conditions because of variations associated with crop and nutrient management factors. The MLRA (Major Land Resource Areas) or geographic units with similar patterns of climate, soils, water resources and land uses offer a unique opportunity for the on-farm assessment of tillage impact on soil C (Tan et al., 2004). Soil C data generated at farmers' fields on a regional basis, covering contrasting climate, soil type and nutrient management, is essential for the development of realistic modeling of soil C dynamics. Moreover, assessment of soil C sequestration potential of NT practice under farmer's field and development of a robust C database on a regional scale may open up the avenue for farmers to generate extra income by selling their C credits in the market (Tan and Lal, 2005).

This study was undertaken to evaluate the long-term impact of NT practices on the SOC sequestration and associated soil quality parameters in comparison to PT and undisturbed woodlot across five MLRAs in the eastern U.S. The main objectives were to compare depthwise distributions of SOC and soil quality parameters among WL, NT and PT practices. This study was conducted under the Midwest Regional Carbon Sequestration Partnership (MRCSP) program launched by the U.S. Department of Energy's Carbon Sequestration Program in 2003.

2. Materials and methods

2.1. Study site description

Paired fields under long-term NT and PT practices were selected within five MLRAs located across Michigan (99 and 111), Ohio (124 and 139) and Pennsylvania (127) during the summer of 2008 (Table 1). Besides NT and PT paired fields, an undisturbed site (control) under forest or woodlot (WL) near the cultivated fields was included in the study to compare the effect of conversion to agricultural land use. The PT fields were managed under chisel plow with occasional moldboard plowing. Detailed descriptions of location, soil taxonomic classification, crop rotation, and soil management are represented in Table 1. The five sites were under corn (*Zea mays* L.)–soybean (*Glycine max* L. Merr.) except for MLRA 127, where corn-alfalfa (*Medicago sativa*) rotation was followed in the PT field. The PT field in MLRA 139 has been under corn for the past years following alfalfa. The tillage practices were the same across the five sites, but the crop rotations were not always consistent across years as farmers often shifted cropping systems depending on climate and market condition. Thus, in this study, profile soil C status of NT and PT fields is a reflection of the differences in field conditions.

2.2. Soil sampling and laboratory analyses

Intact soil core samples were collected from each field and MLRA using a hammer-driven probe from depth increments of 0 to 5, 5 to 10, 10 to 30, 30 to 50 and 50 to 60 cm. Soil bulk density (ρ_b)

Table 1
Site information and soil and management characteristics of paired no-tillage and plow tillage fields per site within each selected MLRA in Michigan, Ohio and Pennsylvania, 2008.

MLRA	Site location	Soil series and slope percent	Taxonomic classification	Management
99	Temperence, MI 41°50.598′N 83°32.234′W	Pewamo clay loam, 0–1	Fine, mixed, active, mesic typic Agriaquolls	10 yr corn-soybean-wheat rotation, wheat: receiving 100 L of liquid fertilizer containing 5% N, 14% P and 4% K and 50 L side dressed of the same mixture and corn receiving 200 L of 28% N liquid fertilizer and 55 Kg K, PT field receiving 55 kg K ha^{-1}
111	Lenawee, MI 41°46.903′N 83°46.001′W	Hoytville clay loam and silty clay loam, 0 to 3%	Fine, illitic, mesic, mollic epiaqualfs	10 yr corn-soybean-wheat, wheat receiving 30 kg N ha^{-1} and 50 L of liquid fertilizer containing 10% N, 34% P and PT: Corn-Soybean receiving 60 kg N ha^{-1}
124	Scioto, OH 39°04.951′N, 83°00.030′W	Genesee, 0–2%	Fine-loamy, mixed, superactive, mesic, fluventic, Eutrudepts	15 yr corn-Soybean receiving 30 kg N, 76 kg P and 100 kg K ha^{-1} every 2 yr
139	Canal Fulton, OH 40°53.484′N 81°33.459′W	Chili Silt loam, 2–6%	Fine-loamy, mixed, active, Mesic typic Hapludalfs	6 yr corn–soybean and PT, 2 yr corn before that alfalfa, NT corn receiving 190 L of liquid fertilizer containing 28% N and for PT corn receiving 185 L of liquid fertilizer mixture containing 10% N, 34% P and current year 65 kg N and 75 kg K ha^{-1} was applied
127	Salisbury, PA 39°44.631′N, 79°0.5.460′W	Cookport loam, 3–8%	Fine-loamy, mixed, active, mesic aquic Fragiudults	30 yr alfalfa receiving 113 kg N ha^{-1} and 54 m^3 of liquid manure; PT corn receiving 284 kg N ha^{-1}

was determined by the method as outlined by Blake and Hartge (1986), which consisted of weighing the soil cores after collection, drying them at 105 °C for 24 h and determining the gravimetric water content to compute the ρ_b value. Bulk soil samples were also obtained from the same five depth increments at each sampling location. As sub sample of the field moist samples were oven-dried at 105 °C to determine the gravimetric soil moisture content. Bulk soil samples were air-dried, finely ground, and sieved with a 2 mm sieve for further analysis. Surface soil samples (0–5 cm) were analyzed for particle-size analysis using the hydrometer method (Gee and Bauder, 1986). Soil pH and EC values of 0–5 cm soil depth were measured electrometrically using a Thermo Scientific Orion 4 star (Thermo Fisher Scientific Inc., Beverly, MA) of 1:2.5 soil/water extract (Thomas, 1996; Rhoades, 1996).

Soil samples were roller ground for fine and homogeneous mixture and analyzed for total soil C and N by the dry combustion method at 900 °C (Nelson and Sommers, 1996) using an elemental analyzer (Elementar Vario MAX; GmbH, Hanau, Germany). Total soil C values were assumed to be equal to SOC. The mass of SOC and N content for a specific soil depth was calculated using Eq. (1) (Lal et al., 1998):

$$\text{Mg C or N ha}^{-1} = \frac{\%\text{C or N} \times \text{B.D.}\,(\text{Mg m}^{-3}) \times \text{depth}\,(\text{m}) \times 10^4\,\text{m}^2\,\text{ha}^{-1}}{100} \quad (1)$$

Soil samples of 0–5 and 5–10 cm soil depths were analyzed for coarse particulate organic matter (CPOM) C and N concentrations as described by Sollins et al. (1999). Briefly, a mixture of 10 g air dry soil samples and 30 mL sodium Hexametaphosphate solution (5 g L^{-1}) in a 50 mL bottle was shaken for 18 h then the suspension was sieved through a 53 μm sieve. The material retained in the sieve was washed with deionized water and transferred quantitatively to a preweighed aluminum pan and oven-dry at 40 °C. The dried mass of sand fraction was weighed (W_s) and finely ground for analysis of total C and N (C_s and N_s). CPOM-C and N concentrations (g C or N kg^{-1} soil) were calculated using Eq. (2).

$$\text{CPOM-C or N}\,(\text{g C or N kg}^{-1}\text{ soil}) = C_s \text{ or } N_s \times W_s \times 10 \quad (2)$$

The nitrate N (NO_3-N) concentration of soil samples from 0–5 to 5–10 cm depths was determined by the extraction of 4 g wet weight soil samples with 2 M KCl solution (Keeney and Nelson, 1987) and subsequently analyzed by a Astoria*2 micro flow system (Astoria-Pacific Inc., Clackamas, OR).

2.3. Statistical analysis

The WL, NT and PT fields were adjacent to each other but were not field replicated. Thus, three random sampling locations in each field were used as pseudo-replicates and the three fields of each MLRA were treated for statistical analyses as if they were randomized. Because the three fields were under similar soil types and slopes, the use of pseudo-replication was considered a viable approach for our on-farm studies. One way ANOVA analyses for different soil depths by MLRA were conducted separately on individual soil physicochemical properties and treatment means were separated by Fisher's LSD (α = 0.05) using SAS (ver. 9.1, SAS 2003). Results were discussed for the individual MLRA due to wide variations across the MLRAs.

3. Results

3.1. Basic soil physicochemical properties

Conversion from forest to agricultural land had a significant impact on soil ρ_b values in most MLRAs (Table 2). Differences in ρ_b between NT and PT were mostly confined to 0–5 and 5–10 cm soil depths under MLRAs 111, 124, 139 and 127. Within 0–5 cm soil depth of MLRA 139, the ρ_b under PT soil lower (1.29 Mg m^{-3}) than under NT soil (1.49 Mg m^{-3}), whereas an opposite trend was observed within MLRA 127. The ρ_b under PT was higher ρ_b (1.51 Mg m^{-3}) than under NT soil (1.25 Mg m^{-3}). Within 5–10 cm soil depth, the soil ρ_b was higher with NT than PT treatment in the case of MLRAs 111 and 139. For the 30–50 and 50–60 cm soil depths, differences in ρ_b between NT and PT were significant only for MLRA 139 where NT had a higher ρ_b than PT soil.

Table 2
Mean (±S.E.) soil bulk density (ρb, Mg m^{-3}) for woodlot (WL), no-tillage (NT) and plow tillage (PT) for five soil depth increments within each selected Major Land Resource Areas (MLRA) in Michigan, Ohio and Pennsylvania.

MLRA	Treatments	Soil depths				
		0–5	5–10	10–30	30–50	50–60
99	WL	0.87 (0.02)[b*]	0.99 (0.09)[b]	1.38 (0.07)[b]	1.62 (0.03)[a]	1.71 (0.04)[a]
	NT	1.43 (0.02)[a]	1.53 (0.03)[a]	1.70 (0.03)[a]	1.66 (0.07)[a]	1.74 (0.03)[a]
	PT	1.36 (0.04)[a]	1.35 (0.06)[a]	1.52 (0.05)[ab]	1.62 (0.05)[a]	1.67 (0.04)[a]
	LSD (0.05)	0.11	0.23	0.18	0.04	0.13
111	WL	1.11 (0.04)[b]	1.28 (0.01)[c]	1.33 (0.08)[b]	1.54 (0.06)[b]	1.76 (0.03)[a]
	NT	1.50 (0.07)[a]	1.62 (0.02)[a]	1.64 (0.05)[a]	1.75 (0.03)[a]	1.74 (0.04)[a]
	PT	1.43 (0.03)[a]	1.51 (0.03)[b]	1.61 (0.05)[a]	1.76 (0.01)[a]	1.75 (0.01)[a]
	LSD (0.05)	0.17	0.07	0.22	0.15	0.09
124	WL	0.30 (0.04)[b]	1.07 (0.44)[a]	1.65 (0.09)[b]	1.79 (0.11)[a]	1.79 (0.09)[a]
	NT	0.93 (0.07)[a]	1.88 (0.04)[a]	1.89 (0.06)[a]	1.87 (0.04)[a]	1.79 (0.02)[a]
	PT	0.77 (0.04)[a]	1.86 (0.04)[a]	1.93 (0.02)[a]	1.84 (0.03)[a]	1.83 (0.09)[a]
	LSD (0.05)	0.28	0.88	0.22	0.24	0.26
139	WL	1.43 (0.05)[ab]	1.56 (0.04)[a]	1.57 (0.07)[a]	1.63 (0.04)[a]	1.71 (0.02)[a]
	NT	1.49 (0.06)[a]	1.61 (0.05)[a]	1.56 (0.04)[a]	1.66 (0.06)[a]	1.75 (0.06)[a]
	PT	1.29 (0.02)[b]	1.32 (0.06)[b]	1.52 (0.02)[a]	1.45 (0.04)[b]	1.42 (0.08)[b]
	LSD (0.05)	0.17	0.18	0.16	0.17	0.20
127	WL	1.26 (0.04)[b]	1.47 (0.04)[a]	1.51 (0.04)[a]	1.68 (0.03)[a]	1.73 (0.04)[a]
	NT	1.25 (0)[b]	1.50 (0.02)[a]	1.56 (0.06)[a]	1.73 (0.05)[a]	1.75 (0.03)[a]
	PT	1.51 (0.04)[a]	1.57 (0.05)[a]	1.42 (0.20)[a]	1.80 (0.01)[a]	1.77 (0.02)[a]
	LSD (0.05)	0.15	0.14	0.43	0.12	0.10

[*] Different letters indicate significant differences among treatments at same soil depth within each MLRA at $P < 0.05$.

Table 3
Mean (±S.E.) sand, silt, and clay content (g kg^{-1}), soil textural class, pH (1:2.5 soil: water extract) and EC (μs cm^{-1}) for woodlot (WL), no-tillage (NT) and plow tillage (PT) within 0–5 cm depth under each selected Major Land Resource Areas (MLRA) in Michigan, Ohio and Pennsylvania.

MLRA	Treatments	Sand	Silt	Clay	Texture	pH	EC
99	WL	482 (28.5)^{b*}	360 (28.3)^{a}	158 (8.30)^{b}	Loam	6.47 (0.13)^{b}	205 (2.59)^{ab}
	NT	589 (34.6)^{a}	253 (28.6)^{b}	158 (16.7)^{b}	Sandy loam	6.02 (0.13)^{c}	407 (104)^{a}
	PT	395 (9.40)^{b}	330 (5.10)^{a}	275 (14.4)^{a}	Clay loam	7.09 (0.07)^{a}	114 (1.78)^{b}
	LSD (0.05)	91.5	74.4	47.1		0.38	207
111	WL	422 (55.0)^{a}	353 (14.5)^{a}	225 (43.3)^{a}	Loam	6.12 (0.12)^{c}	165 (3.98)^{a}
	NT	389 (9.40)^{a}	311 (9.40)^{b}	300 (10.0)^{a}	Clay loam	6.56 (0.06)^{b}	162 (4.40)^{a}
	PT	355 (15.1)^{a}	337 (7.80)^{ab}	308 (8.30)^{a}	Clay loam	6.91 (0.04)^{a}	146 (64.3)^{a}
	LSD (0.05)	115	37.8	88.1		0.28	129
124	WL	432 (31.1)^{a}	401 (47.7)^{a}	167 (16.7)^{b}	Loam	7.08 (0.08)^{a}	325 (55.9)^{a}
	NT	204 (27.7)^{b}	521 (31.9)^{a}	275 (14.4)^{a}	Clay loam	6.94 (0.07)^{a}	75.8 (9.28)^{b}
	PT	348 (11.6)^{a}	469 (22.8)^{a}	183 (16.7)^{b}	Loam	7.00 (0.03)^{a}	94.4 (2.51)^{b}
	LSD (0.05)	86.3	123	55.2		0.23	113
139	WL	277 (42.4)^{a}	590 (46.8)^{a}	133 (8.30)^{b}	Silt loam	5.47 (0.24)^{a}	79.9 (16.0)^{b}
	NT	330 (23.2)^{a}	537 (30.2)^{a}	133 (8.30)^{b}	Silt loam	5.91 (0.20)^{a}	74.6 (12.4)^{b}
	PT	315 (13.8)^{a}	502 (6.60)^{a}	183 (16.7)^{a}	Silt loam	5.77 (0.06)^{a}	620 (113)^{a}
	LSD (0.05)	100	112	40.8		0.63	229
127	WL	449 (6.40)^{b}	410 (14.7)^{a}	142 (8.30)^{ab}	Loam	6.20 (0.10)^{ab}	143 (11.1)^{b}
	NT	561 (10.7)^{a}	339 (12.5)^{b}	100 (14.4)^{b}	Sandy loam	5.97 (0.14)^{b}	688 (260)^{a}
	PT	476 (26.3)^{b}	324 (16.2)^{b}	200 (25.0)^{a}	Loam	6.62 (0.23)^{a}	176 (26.2)^{ab}
	LSD (0.05)	58.2	50.3	60.0		0.56	522

* Different letters indicate significant differences among treatments within each MLRA at $P < 0.05$.

Distributions of particle-size fractions (sand, silt and clay) showed an inconsistent trend among treatments for all MLRAs (Table 3). The NT soils had a higher sand content than PT and WL soils under MLRAs 99 and 127, whereas the NT soil under MLRA 124 had a lower sand content (204 g kg^{-1}) than PT (348 g kg^{-1}) and WL (432 g kg^{-1}). The silt content in NT and PT were only different under MLRA 99, where NT soil had a lower silt content of 253 g kg^{-1} than PT (330 g kg^{-1}) and WL (360 g kg^{-1}) soils. In most MLRAs (99, 139 and 127), clay content was higher under PT treatment than NT. However, an opposite trend was found under MLRA 124, where NT soil had higher clay content (275 g kg^{-1}) than PT soil (183 g kg^{-1}). Soil textural class ranged from sandy loam to clay loam except for MLRA 139, where the textural class for the three landuse systems was silt loam.

Soil pH values were significantly different under MLRAs 99, 111, 139 and 127 and NT soil had a lower soil pH than PT soils in all cases (Table 4). However, differences in soil EC were only significant between NT and PT under 99 and 139. Under MLRA 99, NT had a higher soil EC value (407 μs cm^{-1}) than PT (114 μs cm^{-1}), whereas in the case of MLRA 139, PT soil had a higher EC value (620 μs cm^{-1}) than NT soil (74.6 μs cm^{-1}).

3.2. Soil profile distribution of SOC and nitrogen

The impact of tillage on SOC concentration was most evident at 0–5 cm soil depth (Table 4). WL soil had higher SOC concentration than NT and PT soils at 0–5 cm depth under four MLRAs (99, 111, 124 and 139), whereas in the same depth, NT soil had significantly

Table 4
Mean (±S.E.) soil organic C concentration (g kg^{-1} soil) for woodlot (WL), no-tillage (NT) and plow tillage (PT) for five soil depth increments within each selected Major Land Resource Areas (MLRA) in Michigan, Ohio and Pennsylvania.

MLRA	Treatments	Soil depths 0–5	5–10	10–30	30–50	50–60
99	WL	66.0 (0.10)^{a*}	56.4 (0.46)^{a}	32.6 (0.48)^{a}	10.1 (0.08)^{a}	6.90 (0.10)^{a}
	NT	30.7 (0.08)^{b}	23.4 (0.07)^{b}	19.7 (0.09)^{b}	8.10 (0.12)^{a}	6.30 (0.13)^{a}
	PT	23.7 (0.08)^{c}	23.6 (0.01)^{b}	22.7 (0.16)^{ab}	14.1 (0.29)^{a}	8.80 (0.18)^{a}
	LSD (0.05)	3.10	9.30	10.3	6.40	4.90
111	WL	51.2 (0.10)^{a}	32.5 (0.25)^{a}	24.9 (0.29)^{a}	11.9 (0.18)^{a}	8.50 (0.22)^{a}
	NT	29.3 (0.03)^{b}	20.3 (0.12)^{b}	14.0 (0.16)^{b}	6.70 (0.06)^{b}	5.40 (0.06)^{a}
	PT	19.5 (0.01)^{c}	20.0 (0.03)^{b}	17.3 (0.13)^{b}	8.60 (0.13)^{ab}	4.00 (0.01)^{a}
	LSD (0.05)	2.10	5.50	7.10	7.10	4.60
124	WL	72.5 (1.28)^{a}	58.8 (1.97)^{a}	38.0 (0.50)^{a}	32.0 (0.43)^{a}	31.3 (0.52)^{a}
	NT	21.7 (0.25)^{b}	17.5 (0.11)^{b}	16.2 (0.05)^{b}	15.3 (0.06)^{b}	17.3 (0.24)^{a}
	PT	26.6 (0.17)^{b}	22.0 (0.12)^{ab}	22.7 (0.26)^{b}	18.9 (0.25)^{b}	19.5 (0.62)^{a}
	LSD (0.05)	26.4	39.4	11.2	10.0	16.8
139	WL	21.3 (0.15)^{a}	14.5 (0.10)^{ab}	10.5 (0.29)^{a}	9.80 (0.30)^{a}	4.20 (0.03)^{ab}
	NT	15.8 (0.07)^{b}	11.4 (0.10)^{b}	8.90 (0.10)^{a}	3.90 (0.03)^{a}	2.80 (0.01)^{b}
	PT	18.9 (0.12)^{ab}	19.3 (0.21)^{a}	11.3 (0.30)^{a}	9.40 (0.31)^{a}	7.50 (0.17)^{a}
	LSD (0.05)	4.10	5.00	8.50	8.70	3.50
127	WL	30.2 (0.20)^{ab}	22.4 (0.16)^{a}	18.0 (0.13)^{a}	13.8 (0.19)^{a}	7.10 (0.09)^{a}
	NT	36.5 (0.43)^{a}	23.1 (0.10)^{a}	15.6 (0.07)^{a}	9.70 (0.22)^{a}	8.80 (0.17)^{a}
	PT	21.8 (0.23)^{b}	19.9 (0.09)^{a}	17.5 (0.17)^{a}	8.60 (0.08)^{a}	6.40 (0.05)^{a}
	LSD (0.05)	10.5	4.10	4.60	6.00	4.00

* Different letters indicate significant differences among treatments at same soil depth within each MLRA at $P < 0.05$.

Table 5
Mean (±S.E.) soil organic C on area basis (Mg ha^{-1}) for woodlot (WL), no-tillage (NT) and plow tillage (PT) for five soil depth increments within each selected Major Land Resource Areas (MLRA) in Michigan, Ohio and Pennsylvania.

MLRA	Treatments	Soil depths					Total
		0–5	5–10	10–30	30–50	50–60	
99	WL	28.8 (0.83)^{a*}	27.7 (2.65)^{a}	44.2 (4.61)^{a}	16.3 (1.05)^{b}	11.7 (1.68)^{a}	129 (3.43)^{a}
	NT	21.9 (0.22)^{b}	18.0 (0.79)^{b}	33.5 (1.14)^{a}	13.4 (1.39)^{ab}	10.9 (2.05)^{a}	104 (3.19)^{b}
	PT	16.1 (0.12)^{c}	15.9 (0.62)^{b}	34.6 (2.86)^{a}	22.7 (4.11)^{a}	14.8 (3.41)^{a}	97.6 (5.14)^{b}
	LSD (0.05)	1.73	5.66	11.1	8.92	8.63	13.9
111	WL	28.4 (1.23)^{a}	20.8 (1.63)^{a}	32.8 (2.24)^{a}	18.5 (3.44)^{a}	14.7 (3.64)^{a}	115 (8.26)^{a}
	NT	22.0 (0.97)^{b}	16.3 (0.84)^{b}	23.0 (3.25)^{b}	11.6 (1.07)^{a}	9.31 (0.93)^{ab}	79.0 (3.79)^{b}
	PT	13.9 (0.36)^{c}	15.2 (0.18)^{b}	27.8 (1.81)^{ab}	15.2 (2.35)^{a}	6.96 (0.11)^{b}	82.3 (5.38)^{b}
	LSD (0.05)	3.21	3.68	2.45	8.59	7.50	21.1
124	WL	9.31 (2.21)^{a}	22.8 (6.90)^{a}	62.1 (7.00)^{a}	56.2 (3.82)^{a}	55.5 (6.93)^{a}	206 (5.62)^{a}
	NT	9.86 (0.37)^{a}	16.4 (0.90)^{a}	42.7 (4.02)^{b}	28.8 (1.46)^{b}	31.1 (4.59)^{a}	143 (17.3)^{b}
	PT	10.2 (0.64)^{a}	20.5 (0.79)^{a}	31.3 (0.86)^{b}	34.8 (4.94)^{b}	35.0 (9.81)^{a}	117 (4.57)^{b}
	LSD (0.05)	4.66	14.0	16.2	12.8	25.7	37.5
139	WL	15.3 (1.30)^{a}	11.2 (0.60)^{a}	16.0 (4.00)^{a}	15.9 (4.77)^{a}	7.13 (0.56)^{ab}	65.5 (8.83)^{a}
	NT	11.7 (0.29)^{b}	9.16 (0.77)^{a}	13.9 (1.74)^{a}	6.56 (0.64)^{a}	4.93 (0.14)^{b}	66.7 (14.2)^{a}
	PT	12.3 (0.93)^{ab}	12.8 (1.88)^{a}	17.3 (4.62)^{a}	13.8 (4.78)^{a}	10.5 (2.15)^{a}	46.3 (1.26)^{a}
	LSD (0.05)	3.25	4.23	12.7	13.6	4.45	33.4
127	WL	18.9 (0.47)^{a}	16.4 (1.00)^{a}	27.1 (1.57)^{a}	23.0 (2.69)^{a}	12.4 (1.67)^{a}	97.8 (3.51)^{a}
	NT	22.8 (2.68)^{a}	17.4 (1.01)^{a}	24.4 (0.19)^{a}	16.6 (3.43)^{a}	15.3 (3.07)^{a}	83.4 (6.05)^{a}
	PT	16.6 (2.20)^{a}	15.6 (0.58)^{a}	24.6 (3.90)^{a}	15.4 (1.50)^{a}	11.3 (0.73)^{a}	96.4 (5.54)^{a}
	LSD (0.05)	6.99	3.06	8.41	9.20	7.13	17.8

* Different letters indicate significant differences among treatments at same soil depth within each MLRA at $P < 0.05$.

higher SOC concentration than PT soils by 30, 50 and 67% under MLRAs 99, 111 and 127, respectively. However under MLRAs 124 and 139, NT soil had lower SOC concentration by 20 and 23% under MLRAs 139 and 124, respectively. The only significant difference in SOC concentration between NT and PT within 5–10 cm soil depth was found under MLRA 139, where PT soil had a higher SOC concentration (19.3 g kg^{-1}) than NT soil (11.4 g kg^{-1}). Within 10–30 and 30–50 cm soil depths, WL had a higher SOC concentration than NT under MLRAs 99, 111, 124, and under MLRAs 111 and 124, respectively. At 50–60 cm soil depth, PT soil had a higher SOC concentration of 7.50 g kg^{-1} than NT soil (2.80 g kg^{-1}) under MLRA 139.

The impacts of NT practice on SOC content by depth were inconsistent and varied among MLRAs (Table 5). Within 0–5 cm soil depth, NT soil had higher SOC content than PT soils by 36 and 58% under MLRAs 99 and 111, respectively. However, WL soils had higher total SOC content than NT soils by 29, 31 and 32% under MLRAs 111, 139 and 99, respectively at 0–5 cm soil depth. Within 5–10 cm soil depth, WL soils had higher SOC content than NT and soils by 28 and 54% under MLRAs 111and 99, respectively. Within 10–30 cm soil depth increment, WL had higher SOC content than NT under MLRAs 111 and 124. However, WL soil had lower SOC content (16.3 Mg ha^{-1}) than PT (22.7 Mg ha^{-1}) within 30–50 cm soil depth under MLRA 99 but WL soil had higher SOC content (56.2 Mg ha^{-1}) than NT (28.8 Mg ha^{-1}) and PT (34.8 Mg ha^{-1}) soils under MLRA 124. At deeper soil profiles (50–60 cm soil depth), the only significant difference between NT and PT soils was found under MLRA 139, where NT soil had lower SOC content (4.93 Mg ha^{-1}) than PT soil (10.5 Mg ha^{-1}). At the same depth increment under MLRA 111, WL soil had higher SOC content (14.7 Mg ha^{-1}) than PT (6.96 Mg ha^{-1}). Considering the whole soil profile (60 cm), WL soils had significantly higher profile SOC content than NT soils by 24, 44 and 46% under MLRAs 99,124 and 111, respectively. NT soil had higher profile SOC content than PT soils by 7, 22 and 44% under MLRAs 99, 124 and 139, respectively, whereas, PT had higher profile SOC content over NT soil by 4 and 16% under MLRAs 111 and 127, respectively.

Within 0–5 cm soil depth, WL soil had higher soil N content than NT and PT soils under MLRAs 99 and 111 (Table 6). At the same depth, total soil N content was higher in NT soil than PT soils by 27, 44 and 54% under MLRAs 99, 127 and 111, respectively. At 5–10 cm soil depth, WL had higher total soil N content than NT by 26 and 55% under MLRAs 111 and 99, respectively. Only within MLRA 99, WL soil had higher N content (4.25 Mg ha^{-1}) than NT (3.17 Mg ha^{-1}) and PT (3.30 Mg ha^{-1}) soils at 10–30 cm depth. Under the same MLRA (99), PT soil had higher soil N content (2.35 Mg ha^{-1}) than NT (1.36 Mg ha^{-1}) at 30–50 cm soil depth. Considering the 60 cm profile depth, WL soil had higher N content than NT soil by 17 and 31% under MLRAs 99 and 111, respectively. Only significant difference in profile N content between NT and PT soil was found under MLRA 99 and NT soil had higher profile N content of 10.5 Mg N ha^{-1} than PT soil (9.42 Mg N ha^{-1}).

3.3. Concentrations of CPOM-C and N

CPOM-C concentration of NT was significantly higher than PT under MLRAs 99, 111 and 127 within 0–5 cm soil depth (Table 7). WL had a higher CPOM-C than NT and/or PT under most MLRAs at the same soil depth increment. Within 5–10 cm soil depth, WL had a higher CPOM-C concentration than NT and PT under MLRA 99 and 111. CPOM-N concentration showed almost same trend like CPOM-C in both soil depths except under 139, where PT (3.28 g kg^{-1}) had a higher CPOM-N than NT (0.99 g kg^{-1}) at 5–10 cm soil depth.

3.4. Soil nitrate nitrogen concentration

Concentration of soil NO_3-N did not show any definite trend across five different MLRAs (Table 8). Within 0–5 cm soil depth under MLRA 99, NT soil had higher NO_3-N concentration (120 μg g^{-1}) than PT soil (5.47 μg g^{-1}), whereas under MLRA 139, PT soil had significantly higher NO_3-N concentration (173 μg g^{-1}) than NT soil (6.68 μg g^{-1}). The same trend was also followed under these MLRAs (99 and 139) at the next depth increment (5–10 cm) also. Under MLRA 99, NT soil had higher NO_3-N concentration of 44.9 μg g^{-1} than PT soil (7.33 μg g^{-1}), whereas, PT soil had higher NO_3-N concentration of 25.1 μg g^{-1} than NT soil (4.43 μg g^{-1}) under MLRA 139.

Table 6
Mean (±S.E.) total soil nitrogen on area basis (Mg ha^{-1}) for woodlot (WL), no-tillage (NT) and plow tillage (PT) for five soil depth increments within each selected Major Land Resource Areas (MLRA) in Michigan, Ohio and Pennsylvania.

MLRA	Treatments	Soil depths					Total
		0–5	5–10	10–30	30–50	50–60	
99	WL	2.30 (0.07)^{a*}	2.55 (0.32)^{a}	4.25 (0.20)^{a}	1.82 (0.13)^{ab}	1.39 (0.17)^{a}	12.3 (0.35)^{a}
	NT	1.92 (0.04)^{b}	1.64 (0.06)^{b}	3.17 (0.05)^{b}	1.36 (0.11)^{b}	1.33 (0.11)^{a}	10.5 (0.09)^{b}
	PT	1.51 (0.01)^{c}	1.51 (0.08)^{b}	3.30 (0.21)^{b}	2.35 (0.30)^{a}	1.78 (0.41)^{a}	9.42 (0.22)^{c}
	LSD (0.05)	0.16	0.67	0.59	0.69	0.92	0.85
111	WL	2.62 (0.12)^{a}	2.10 (0.14)^{a}	3.29 (0.25)^{a}	1.94 (0.29)^{a}	2.04 (0.52)^{a}	12.0 (1.02)^{a}
	NT	2.28 (0.09)^{b}	1.67 (0.04)^{b}	2.74 (0.36)^{a}	1.52 (0.22)^{a}	1.60 (0.37)^{a}	9.18 (0.27)^{b}
	PT	1.48 (0.04)^{c}	1.61 (0.06)^{b}	2.95 (0.07)^{a}	1.97 (0.26)^{a}	1.17 (0.06)^{a}	9.80 (0.59)^{ab}
	LSD (0.05)	0.31	0.31	0.89	0.89	1.29	2.55
124	WL	0.71 (0.17)^{a}	1.58 (0.46)^{a}	3.91 (0.90)^{a}	3.35 (0.58)^{a}	3.26 (0.80)^{a}	12.8 (1.38)^{a}
	NT	0.99 (0.05)^{a}	1.65 (0.33)^{a}	2.87 (0.19)^{a}	2.71 (0.11)^{a}	1.73 (0.15)^{a}	12.5 (0.95)^{a}
	PT	0.97 (0.06)^{a}	1.98 (0.11)^{a}	4.09 (0.33)^{a}	3.07 (0.42)^{a}	2.39 (0.27)^{a}	9.94 (0.36)^{a}
	LSD (0.05)	0.37	1.15	1.94	1.45	1.71	3.42
139	WL	1.34 (0.11)^{a}	1.10 (0.06)^{a}	1.52 (0.25)^{a}	1.33 (0.23)^{a}	1.49 (0.37)^{a}	6.78 (0.74)^{a}
	NT	1.15 (0.05)^{a}	0.89 (0.03)^{a}	1.31 (0.10)^{a}	0.84 (0.05)^{a}	0.82 (0.09)^{a}	6.32 (1.20)^{a}
	PT	1.30 (0.08)^{a}	1.22 (0.20)^{a}	1.57 (0.42)^{a}	1.21 (0.31)^{a}	1.01 (0.20)^{a}	5.01 (0.18)^{a}
	LSD (0.05)	0.30	0.42	1.00	0.78	0.87	2.83
127	WL	1.75 (0.05)^{ab}	1.79 (0.22)^{a}	2.54 (0.17)^{a}	2.19 (0.39)^{a}	1.33 (0.22)^{a}	9.60 (0.64)^{a}
	NT	2.29 (0.31)^{a}	1.70 (0.11)^{a}	2.44 (0.02)^{a}	1.53 (0.28)^{a}	1.53 (0.24)^{a}	8.46 (0.17)^{a}
	PT	1.59 (0.10)^{b}	1.47 (0.01)^{a}	2.34 (0.32)^{a}	1.69 (0.24)^{a}	1.37 (0.07)^{a}	9.50 (0.54)^{a}
	LSD (0.05)	0.67	0.49	0.73	1.07	0.67	1.71

[*] Different letters indicate significant differences among treatments at same soil depth within each MLRA at $P < 0.05$.

4. Discussion

Increase in soil ρ_b due to the conversion of forest (WL) to agricultural land usage (NT and PT) was evident under MLRAS 99, 111 and 124 up to 30 cm soil depth (Table 2). Particularly only under MLRA 139, NT practice increased soil ρ_b value up to 60 cm soil depth; however, the difference was not significant within 10–30 cm. MLRA 139 had distinctly different soil textural class of silt loam whereas other MLRAs had soil textural class varies from sandy loam to clay loam (Table 3). These findings did not support previous conclusions that tillage practice had either no effect or limited effect up to surface 30 cm soil depth (Puget and Lal, 2005; Hermle et al., 2008).

Generally lower soil pH under NT practice (MLRAs 99, 111 and 127) may be attributed to the formation of organic acids and nitrification of NH_4^+ from NH_4NO_3 fertilizer application and mineralization of crop residues (Ismail et al., 1994). Generally, soil EC becomes lower with NT practice due to increased water movement and higher soil aggregation (Dalal, 1989); however, soil EC values at surface depth did not show any consistent trend across MLRAs.

Increase in SOC concentration with NT practice is site specific and limited within surface soil (Liebig et al., 2004; Blanco-Canqui and Lal, 2008). Puget and Lal (2005) compared SOC stock of 56-paired NT and PT treatments and out of that 42 had a positive

Table 7
Mean (±S.E.) coarse particulate organic matter associated carbon (CPOM-C) and nitrogen (CPOM-N) concentration (g kg^{-1}soil) for woodlot (WL), no-tillage (NT) and plow tillage (PT) for two soil depth increments within each selected Major Land Resource Areas (MLRA) in Michigan, Ohio and Pennsylvania.

MLRA	Treatments	CPOM-C		CPOM-N	
		0–5	5–10	0–5	5–10
99	WL	202 (11.5)^{a*}	139 (23.5)^{a}	12.6 (0.81)^{a}	9.61 (1.88)^{a}
	NT	92.4 (3.38)^{b}	46.8 (4.43)^{b}	5.88 (0.25)^{b}	3.43 (0.29)^{b}
	PT	47.7 (6.93)^{c}	40.0 (1.74)^{b}	2.86 (0.47)^{c}	2.55 (0.12)^{b}
	LSD (0.05)	27.6	47.8	1.93	3.82
111	WL	128 (15.7)^{a}	60.9 (7.22)^{a}	8.81 (0.94)^{a}	4.61 (0.65)^{a}
	NT	79.3 (8.83)^{b}	31.6 (2.95)^{b}	6.05 (0.55)^{b}	2.71 (0.26)^{b}
	PT	33.0 (1.28)^{c}	32.4 (2.53)^{b}	2.19 (0.10)^{c}	2.21 (0.12)^{b}
	LSD (0.05)	36.1	16.4	2.19	1.42
124	WL	440 (159)^{a}	185 (97.2)^{a}	30.6 (12.4)^{a}	11.1 (7.16)^{a}
	NT	40.7 (10.0)^{b}	20.4 (2.92)^{a}	2.90 (0.76)^{b}	1.54 (0.23)^{a}
	PT	58.0 (3.38)^{b}	26.5 (2.54)^{a}	4.24 (0.26)^{b}	1.82 (0.20)^{a}
	LSD (0.05)	319	194	24.8	14.3
139	WL	63.7 (7.67)^{a}	39.1 (14.1)^{a}	4.03 (0.51)^{a}	1.74 (0.42)^{b}
	NT	37.8 (3.66)^{b}	15.7 (1.55)^{a}	2.67 (0.32)^{a}	0.99 (0.05)^{b}
	PT	51.3 (4.77)^{ab}	45.3 (8.26)^{a}	3.45 (0.38)^{a}	3.28 (0.55)^{a}
	LSD (0.05)	19.5	32.9	1.43	1.38
127	WL	75.4 (8.81)^{ab}	40.9 (5.53)^{a}	4.95 (0.37)^{b}	2.92 (0.33)^{a}
	NT	123 (13.0)^{a}	52.7 (7.07)^{a}	9.77 (1.26)^{a}	3.64 (0.54)^{a}
	PT	68.2 (19.6)^{b}	63.9 (36.0)^{a}	4.57 (1.26)^{b}	4.22 (0.94)^{a}
	LSD (0.05)	50.2	35.9	3.63	2.26

[*] Different letters indicate significant differences among treatments at same soil depth within each MLRA at $P < 0.05$.

Table 8
Mean (±S.E.) soil inorganic nitrate nitrogen (NO_3-N) concentration (μg g^{-1} dry soil) for woodlot (WL), no-tillage (NT) and plow tillage (PT) for two soil depth increments within each selected Major Land Resource Areas (MLRA) in Michigan, Ohio and Pennsylvania.

MLRA	Treatments	Soil depths	
		0–5	5–10
99	WL	5.47 (0.12)[b*]	8.22 (1.11)[b]
	NT	120 (42.8)[a]	44.9 (7.52)[a]
	PT	5.47 (1.61)[b]	7.33 (1.00)[b]
	LSD (0.05)	85.6	15.3
111	WL	11.1 (3.43)[a]	5.25 (1.58)[a]
	NT	12.0 (4.28)[a]	5.44 (2.33)[a]
	PT	5.47 (1.83)[a]	7.09 (1.54)[a]
	LSD (0.05)	11.6	6.40
124	WL	53.7 (2.60)[a]	39.1 (28.7)[a]
	NT	3.19 (0.93)[b]	3.02 (0.40)[a]
	PT	4.78 (1.59)[b]	1.68 (0.20)[a]
	LSD (0.05)	6.36	57.3
139	WL	5.53 (3.45)[b]	1.37 (1.13)[b]
	NT	6.68 (2.49)[b]	4.43 (1.78)[b]
	PT	173 (47.1)[a]	25.1 (7.92)[a]
	LSD (0.05)	19.9	16.4
127	WL	8.22 (0.63)[a]	13.6 (3.78)[a]
	NT	177 (87.8)[a]	12.5 (2.87)[a]
	PT	29.7 (8.29)[a]	19.2 (9.63)[a]
	LSD (0.05)	176	21.5

[*] Different letters indicate significant differences among treatments at same soil depth within each MLRA at $P < 0.05$.

increase and less than 11 had a negative response. Total soil N concentration simply followed the trend of SOC concentration (Tables 4 and 5). However, it should be considered that there were significant differences in nitrogen fertilizer application between NT and PT practices, even under the same MLRAs. When SOC concentration was expressed in mass per area basis, higher SOC content with NT practice was observed only under two MLRAs (99 and 111). Surprisingly, whole soil profile SOC stock (up to 60 cm soil depth) was not different in any of the five MLRAs. Baker et al. (2007) remarked that the previous notion of higher SOC concentration associated with NT practice resulted due to the consideration of shallow soil sampling depth and studies involving deeper sampling generally show no SOC sequestration advantage for conservation tillage.

Soil disturbance has a strong influence on CPOM associated C and N in four out of five MLRAs (except 127) (Table 6). Between NT and PT, CPOM associated C and N was mostly within 0–5 cm soil depth under MLRAs 99, 111 and 127. NT and PT have a significant difference in introduction of crop residues into the soil. Under NT practice, crop residues are left on the soil surface whereas residues are incorporated into the soil during tillage. As stable isotope study showed that the majority of C from corn residues accumulated in the upper 5 cm under NT management (Balesdent et al., 1990; Angers et al., 1995; Olchin et al., 2008). Conversion to NT farming increased (MLRA 99), decreased (MLRA 127) or had no effect on soil NO_3-N concentrations. Sharifi et al. (2008) found that tillage practice increased mineralizable N only at one of the four sites, and conclude that measurable response of NT on mineralizable N needs longtime observation with consideration of its wide spatial variability.

5. Conclusion

Theses results showed that NT farming increased the surface SOC content of specific soil types but the net effect of SOC for the whole soil profile (0–60 cm) is not significantly different than plow tillage across soils under five MLRAs in eastern United States. NT farming also increased surface soil total N and CPOM associated C and N concentration compared to plow tillage of specific soil types. Impact of NT farming on soil C and associated soil parameters are confined within surface soils. Previous studies indicated a significant difference in SOC content between NT and PT soils considered only surface soil depths (<30 cm). This study suggests that consideration of whole soil profile SOC content is necessary to evaluate the impact of NT farming. Moreover, simultaneous measurement of soil quality parameters will provide insight into the SOC sequestration potentials under NT farming. The idea that no-tillage influence soil organic C sequestration needs reevaluation based on different soil types, climatic conditions and cropping pattern.

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