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Soil organic carbon and nitrogen in a Mollisol in central Ohio as affected by tillage and land use

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Abstract

Minimum tillage practices are known for increasing soil organic carbon (SOC). However, not all environmental situations may manifest this potential change. The SOC and N stocks were assessed on a Mollisol in central Ohio in an 8-year-old tillage experiment as well as under two relatively undisturbed land uses; a secondary forest and a pasture on the same soil type. Cropped systems had 51 ± 4 (equiv. mass) Mg ha^{-1} lower SOC and lower 3.5 ± 0.3 (equiv. mass) Mg ha^{-1} N in the top 30 cm soil layer than under forest. Being a secondary forest, the loss in SOC and N stocks by cultivation may have been even more than these reported herein. No differences among systems were detected below this depth. The SOC stock in the pasture treatment was 29 ± 3 Mg ha^{-1} greater in the top 10 cm layer than in cultivated soils, but was similar to those under forest and no-till (NT). Among tillage practices (plow, chisel and NT) only the 0–5 cm soil layer under NT exhibited higher SOC and N concentrations. An analysis of the literature of NT effect on SOC stocks, using meta-analysis, suggested that NT would have an overall positive effect on SOC sequestration rate but with a greater variability of what was previously reported. The average sequestration rate of NT was 330 kg SOC ha^{-1} year^{-1} with a 95% confidence interval ranging from 47 to 620 kg SOC ha^{-1} year^{-1}. There was no effect of soil texture or crop rotation on the SOC sequestration rate that could explain this variability. The conversion factor for SOC stock changes from plow to NT was equal to 1.04. This suggests that the complex mechanisms and pathways of SOC accrual warrant a cautious approach when generalizing the beneficial changes of NT on SOC stocks.

Keywords: Soil carbon sequestration; Nitrogen stock; No till; Pasture; Forest; Meta-analysis; Soil quality; Conservation tillage

1. Introduction

Conversion of natural ecosystems to agriculture as well as increasing intensity of tillage are known to decrease soil organic matter (SOM) levels and contribute significantly to the increase in atmospheric CO_2 concentration (Lal et al., 1998). Between 1850 and 1995, SOM mineralization emitted $136 \pm 55 \times 10^{15}$ g of C to the atmosphere (Houghton, 1995; Watson et al., 2001). Changes in SOM by different agricultural land uses and practices have been extensively reviewed by Mann (1986), Davidson and Ackerman (1993), Guo and Gifford (2002), and Murty et al. (2002). Guo and Gifford (2002) reported that soils lost 42 and 59% of their soil organic carbon (SOC) stock upon conversion from forest to crop and from grassland to crop, respectively. In contrast, Mann (1986) calculated losses <20% of the initial stock, which was corroborated by Kern and Johnson (1993) and Murty et al. (2002) who evaluated the decrease of SOC stock in the major

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US cropland soils at ca. 16 and 22–25%, respectively. However, Davidson and Ackerman (1993) argued that calculations made on a fixed soil depth instead of an equivalent mass of soil underestimated the changes in SOC stock. With the objective of reducing net emission of CO_2 and other greenhouse gases (GHGs), soil C sink capacity has been debated (Swift, 2001; West and Marland, 2002), i.e., can the "lost C" be re-sequestered in soils and if so, how and to what extent?

Three main strategies for SOC sequestration in the biosphere are: (i) enhancing the re-growth of perennial vegetation through conversion of cropland to grassland or forestland, (ii) increasing the net primary productivity and therefore the amount of residue returned to the soil, mainly through intensification of agricultural inputs: fertilizer, irrigation, manuring, and (iii) adopting conservation tillage especially no tillage (NT). Post and Kwon (2000) reported that changes in land use to perennial vegetation may potentially sequester C at a rate of 300–350 kg C ha^{-1} $year^{-1}$. However, they acknowledged that this increase was too small to counteract the "anthropogenically released" C in the global C cycle. Several studies have shown that intensification of farming systems augments SOC levels mainly by increasing the amount of biomass produced and the amount of residues returned (Larson et al., 1972; Zielke and Christenson, 1986; Havlin et al., 1990; Campbell and Zetner, 1993; Follett, 2001). However, some researchers have pointed out that these approaches may not be as efficient as perceived when fluxes of all GHGs, especially the hidden C costs of agricultural intensification, are taken into account (Robertson et al., 2000; Schlesinger, 2000a,b).

Conservation tillage practices, especially NT, can improve SOC and other soil nutrient stocks. Conservation tillage was developed primarily to combat soil erosion by developing a protective mulch layer of crop residues at the soil surface. Consequently, the repetitive use of this technique profoundly affects the incorporation and depth distribution of SOC, as well as the whole ecology and functioning of soil (Kladivko, 2001). No tillage impacts SOC stock in two ways: (i) by reducing disturbance which favors the formation of soil aggregates and protects SOC encapsulated inside these stable aggregates from rapid oxidation (Chaney et al., 1985; Elliott, 1986; Beare et al., 1994; Six et al., 2000) and (ii) by modifying the local edaphic environment: bulk density, pore size distribution, temperature, water and air regime that might also restrict SOC biodegradation (Mielke et al., 1986; Kay and VandenBygaart, 2002). The literature is replete with studies that show an increase in SOC stock with conversion to NT, at least in the surface soil (e.g. Blevins et al., 1983; Dick, 1983; Dick et al., 1986, 1991; Doran, 1980; Lal et al., 1990). Paustian et al. (1997) and Lal et al. (1998) summarized the rate of accumulation of SOC stock under NT at 300–800 kg SOC ha^{-1} $year^{-1}$. However, under some conditions, especially in fine-textured soils, there may be little or no increase in SOC stock, especially at a depth greater than the plow layer (Mielke et al., 1986; Dalal, 1988; Angers et al., 1995,1997; Wander et al., 1998).

The present study was undertaken to determine how contrasting agricultural land uses and tillage practices might affect SOC sequestration in a fine-textured Mollisol in central Ohio. We determined the distribution and stocks of SOC and N through the soil profile and compared our data with those reported in the literature in which studies were carried out on paired experiments of NT versus plow till.

2. Materials and methods

A tillage experiment was initiated in Autumn 1993 to determine the effect of three tillage practices [chisel till (CT), moldboard plow till (PT) and NT] on corn (*Zea mays*) yield and plant nutrients. The experiment was located at the Don Scott Experimental Farm, Columbus, OH (40°04′30′′N; 83°04′W) on a Kokomo silty clay loam (somewhat poorly drained, fine, mixed, mesic, Typic Argiaquolls) (McLoda and Parkinson, 1980). The experimental plot was divided in two blocks (west and east) on which corn and soybean (*Gtycine max*) were cropped in alternate years. The above-ground crop residue returned was 8–10 Mg ha^{-1} $year^{-1}$ during the corn cycle and 2–3 Mg ha^{-1} during the soybean cycle. Each block was divided into 12 subplots of 17.5 m × 22.5 m corresponding to three tillage treatments replicated four times. Soil samples were collected in December 2001 in the west block after corn harvest following 8 years of consecutive tillage treatment. A soil core (7.6 cm in diameter) was taken from the center of each subplot, using a truck-mounted hydraulic probe to 70 or 80 cm depth. The core was divided into 5 cm increments to 40 cm depth and 10 cm increments thereafter. Two adjacent areas, located within 1 km of the tillage experiment on the same soil type, were also sampled: one managed as grazed pasture for at least 15 years and the second as a woodlot (ca. 80-year-old secondary forest of mixed hardwood). Predominant species included a mixture of orchard grass (*Dactylis glomeratd*) and red clover (*Trifoliumpratense*) in pasture, and maple (*Acer* spp.), oak (*Quercus* spp.) and hickory (*Carya glabera*) in the woodlot. Three distinct soil cores were taken from these plots as pseudo field replicates.

The coarse crop residue corresponding to 2001 harvest was not included in the soil samples. Similarly, the fresh litter in the forest and the green grass in the pasture plot were also removed before taking soil samples. Soil samples were brought to the lab, weighed (field moist weight), dried at 60 °C and weighed again. Subsamples were taken and weighed after 48 h at 105 °C for computing the bulk density. Total C and N concentrations (dry combustion method on a Thermoquest NC soil 1100) were determined after sieving the samples through a 2-mm sieve and fine grinding using a ball-mill grinder. No residues were removed. No carbonates were detected when an acid -drop test was used on the samples. Thus total C was assumed to be equivalent to SOC. The C and N stocks were then calculated by multiplying the C or N concentration by the bulk density and expressed in Mg ha^{-1}.

2.1. Data analysis

Analysis of variance (ANOVA) was used to assess the treatment effects (land use and tillage) and depth, or treatment only, on soil bulk density, SOC and N concentrations and stocks. Tukey's mean difference test was used at the 5% probability level to separate treatments (SAS Institute, 1999).

Comparison of SOC stock between NT and PT was made for 28 published studies reporting 56-paired experiments. We selected studies reporting SOC stock on an area basis or including data of both bulk density and SOC concentration. A linear regression analysis was performed between SOC stock under PT and NT by using the linear model procedure in SAS with a fixed intercept equal to zero.

A meta-analysis of literature data was conducted to provide a comprehensive evaluation of the effect of NT on SOC. Meta-analysis allows synthesis of quantitatively independent studies to answer a specific question in different environments (Gurevitch and Hedges, 1999, 2001). This tool has already been used in the field of soil science to address questions related to SOC stock changes under different land uses and management (Johnson and Curtis, 2001; Guo and Gifford, 2002).

Because of the diverse situations (e.g., duration of the experiment, cropping rotation, soil type, initial SOC stock, location, etc.) the rate of SOC sequestration (difference in SOC stock between NT and PT divided by the duration of the experiment in years) was chosen as the response variable. Most of the studies did not report consistent measures of variance, thus an 'unweighted' meta-analysis (i.e., equal variance) was conducted. The mean and 95% confidence interval were calculated using Meta-Win 2 software (Rosenberg et al., 2000) after a bias corrected bootsrapping procedure (Dixon, 2001; Manly, 1997). The dataset was partitioned into categories corresponding to soil type and cropping intensity. Two soil type categories were fine-textured soils (clay content >30%) and coarse-textured soils. Two cropping intensity categories were based on the amount of crop residue biomass returned: (1) low; wheat (*Triticum aestivum*)–fallow rotation, continuous soybean (*Glycine max*) or corn silage, and (2) high; continuous corn or sorghum (*Sorghum bicolor*).

3. Results and discussion

3.1. Soil bulk density

Tillage treatment had no impact on soil bulk density. Lower bulk density was observed in forest compared to cultivated plots and the pasture to 30 cm depth (Fig. 1). Unger (1982) reported that bulk density of a Pullman clay loam in Texas was not impacted by 36 years of different tillage treatments (mainly disk tillage). In contrast, other physical parameters of soil quality (dry and water-stable aggregate size distribution, resistance to rupture and penetration) were modified. Similarly, Lal (1999) also reported that tillage did not have any effect

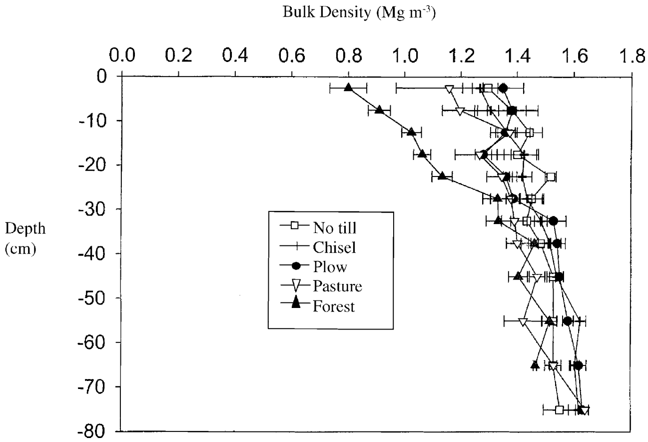

Fig. 1. Soil profile bulk density under plow till, chisel till, no till, pasture and forest. Error bars represent standard error of $n = 4$ for tilled soils and $n = 3$ for pasture and forest soils.

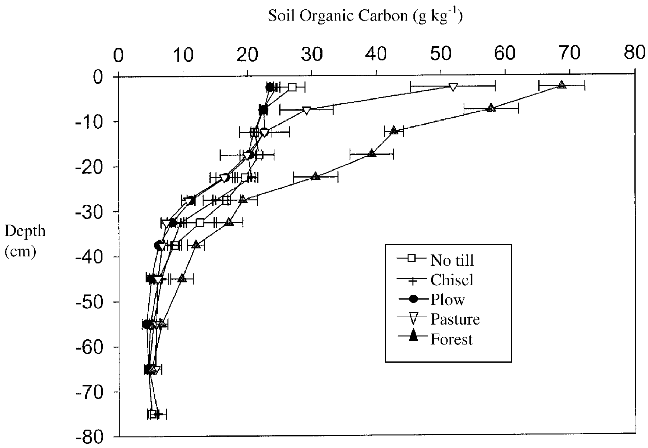

Fig. 2. Soil profile organic carbon concentration under plow till, chisel till, no till, pasture and forest. Error bars represent standard error of $n = 4$ for tilled soils and $n = 3$ for pasture and forest soils.

on soil bulk density of a Mollic Ochraqualf in Ohio.

3.2. Soil organic carbon and nitrogen concentrations

Distribution of C and N concentrations in the soil profile are shown in Figs. 2 and 3. Both SOC and N distributions were strongly stratified with depth in the forest soil, which had the highest C and N concentrations in the top 30 cm. Differences among land uses and tillage practices diminished below 30 cm and no differences were observed below 50 cm. In comparison to cropland, pasture soil contained greater C and N but only in the 0–5 and 5–10 cm soil layers. Among the three tillage treatments, SOC and N concentrations were significantly different, but only in the 0–5 cm soil layer (Table 1). Between CT and PT, neither SOC nor N differed at any depth.

Similar results showing different SOC and N concentrations among tillage systems in the top 10 cm of clayey soils have been reported. For instance, Dick (1983) and Lal et al. (1990) reported for a Mollic Ochraqualf in northwestern Ohio that even after 18 and 12 years of continuous cultivation with NT, an increase in SOC concentration by 15% compared with PT occurred only in the first 5 cm layer. Higher but

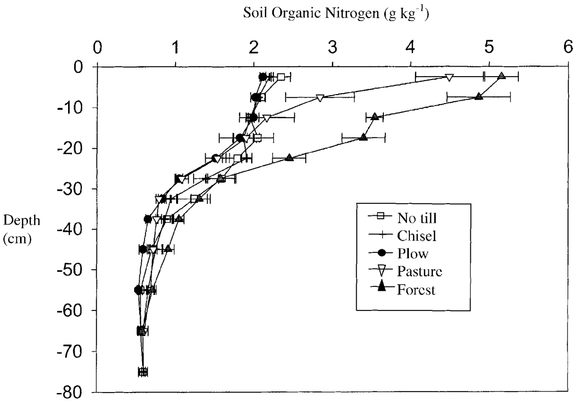

Fig. 3. Soil profile nitrogen concentration under plow till, chisel till, no till, pasture and forest. Error bars represent standard error of $n = 4$ for tilled soils and $n = 3$ for pasture and forest soils.

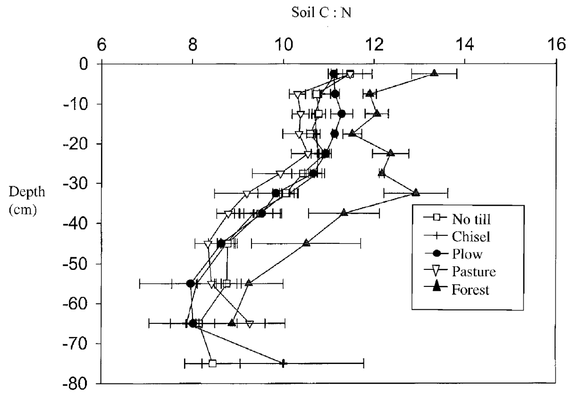

Fig. 4. Soil profile C:N ratio under plow till, chisel till, no till, pasture and forest. Error bars represent standard error of $n = 4$ for tilled soils and $n = 3$ for pasture and forest soils.

non-significant concentrations were observed in NT versus PT between 5 and 20 cm depths and no differences between the two treatments below 20 cm depth. Wander et al. (1998) and Needelman et al. (1999) found similar results in a large number of clayey soils in Illinois where the top 0–5 cm layer under NT contained greater C and N concentrations than under PT. Similar results have been reported in fine-textured soils of different pedoclimatic conditions, e.g., for a Grundy silty clay soil in Kansas (Havlin et al., 1990); the cool and humid environment in Canada (Carter and Rennie, 1982; Angers et al., 1995, 1997) and in Vertisols in Australia under tropical and subtropical climate (Dalal, 1988; Chan et al., 2002; Haynes and Beare, 1996).

The C:N ratio was affected by both land use and tillage (Fig. 4). Forest soil had the highest C:N ratio for all sampling depths, and pasture the lowest values (except for 0–5 cm depth). This effect was similar to that reported by Franzluebbers et al. (2000) and values mainly reflected different qualities of organic residues entering the SOM pool and could be attributed to

Table 1
Cumulative stock of SOC and N in plow till, chisel till, no till, pasture and forest

Treatment Depth (cm)	Soil organic carbon stock ($Mg ha^{-1}$)					Stock of N ($Mg ha^{-1}$)				
	Plow till	Chisel till	No till	Pasture	Forest	Plow till	Chisel till	No till	Pasture	Forest
0–5	16 c	16 c	19 bc	44 a	27 b	1.4 b	1.4 b	1.6 b	3.7 a	2.1 b
0–10	32 b	30 b	35 b	61 a	54 a	2.8 b	2.7 b	3.1 b	5.3 a	4.3 a
0–15	47 b	44 b	50 b	75 a	76 a	4.2 b	4.1 b	4.5 b	6.7 a	6.1 a
0–20	62 c	59 c	65 bc	88 ab	97 a	5.5 b	5.4 b	5.9 b	7.9 a	7.9 a
0–25	76 b	73 b	81 b	99 ab	114 a	6.8 b	6.8 b	7.4 ab	9.0 a	9.3 a
0–30	88 b	84 b	94 b	107 b	127 a	7.9 NS	7.8 NS	8.6 NS	9.7 NS	10.4 NS
0–35	98 b	91 b	103 b	112 b	139 a	8.8 NS	8.5 NS	9.5 NS	10.3 NS	11.2 NS
0–40	105 b	98 b	110 b	119 b	147 a	9.5 NS	9.1 NS	10.3 NS	11.0 NS	12.0 NS
0–50	112 b	108 b	120 b	127 b	161 a	10.3 NS	10.3 NS	11.3 NS	12.1 NS	13.3 NS
0–60	120 b	117 b	128 b	136 b	173 a	11.2 NS	11.4 NS	12.3 NS	13.1 NS	14.7 NS
0–70	137 b	126 b	135 b	147 b	178 a	13.1 NS	12.6 NS	13.1 NS	14.3 NS	15.2 NS
0–80	139 NS	134 NS	143 NS	149 NS		13.3 NS	13.5 NS	14.1 NS	14.6 NS	

Different letters in the same row represent a significant difference in stock among treatments, according to Tukey's mean significance test at $P < 0.05$. NS is not significant.

contrasting vegetation covers. Tillage treatment also altered soil C:N ratio with lowest associated with minimum tillage practices. The lower C:N ratio in CT and NT than in PT may have been due to a relatively higher contribution of root than aboveground inputs. The high potential N mineralization and microbial biomass under minimum tillage, as reported by other researchers (Doran, 1980; Franzluebbers and Arshad, 1997), may have also led to this change in the C:N ratio.

3.3. Soil organic carbon and nitrogen stocks

There were no differences in stocks of SOC and N among the three tillage systems throughout the soil profile (Table 1). In the whole soil profile (0–80 cm depth) this Mollisol stored an average of 139 Mg C ha^{-1} and 13.6 Mg N ha^{-1} when cultivated.

There were differences in SOC and N stocks between cultivated and uncultivated soils (Table 1). Pasture soil contained the highest SOC and N stocks in the top 5 cm layer reflecting the larger grass root density found in this layer. Pasture soil had 44 Mg C ha^{-1} and 3.7 Mg N ha^{-1}, which was more than twice the SOC and N stocks in cultivated soils and more than 1.5 times that in the forest soil. The difference in SOC and N stocks between pasture and cultivated soils decreased with increasing sampling depth. The contribution of the deeper soil layers to the SOC and N stocks was small and similar to that in cropped soils below 10 cm depth. In forest, the soil layers between 10 and 40 cm depth contributed almost equally to the SOC and N stocks as the 0–5 cm soil layer. Thus, in the whole soil profile (0–80 cm depth or 70 cm under forest soil) the soil under forest contained significantly greater SOC stock than that under pasture and the cultivated soils: 178 Mg C ha^{-1} in forest versus 136 ± 8 Mg C ha^{-1} in the other treatments. When SOC and N stocks were computed on an equivalent soil mass rather than on a fixed depth basis, similar differences among treatments occurred (Table 2). In 0–30 cm soil depth cropped soils had an average of 63% of the SOC stock as that under forest. Below 30 cm, no further N or C losses were observed in comparison to the reference stock under forest, suggesting that changes in SOC and N stocks upon cultivation occurred mainly in the A horizon. Being a secondary forest, the loss in SOC and N stocks by

Table 2
Stock of SOC on an equivalent soil mass referenced to plow till at 0–20 cm and at 0–30 cm depth

	Equivalent soil layer depth of 0–20 cm in plow till						Equivalent soil layer depth of 0–30 cm in plow till					
	Soil mass (Mg ha^{-1})	Equivalent thickness (cm)	SOC stock (Mg ha^{-1})	N stock (Mg ha^{-1})	Percentage of forest SOC stock (%)	Percentage of forest N stock (%)	Soil mass (Mg ha^{-1})	Equivalent thickness (cm)	SOC stock (Mg ha^{-1})	N stock (Mg ha^{-1})	Percentage of forest SOC stock (%)	Percentage of forest N stock (%)
Plow till	2688	20	62 (±3) b	6 (±0.2) b	53	57	4064	30	88.5 (±2.6) b	7.9 (±0.2) b	64	69
Chisel till	2688	20	59 (±2) b	5 (±0.1) b	50	56	4064	29.7	83.3 (±2.5) b	7.7 (±0.2) b	60	67
No till	2688	19.5	64 (±1) b	6 (±0.1) b	54	60	4064	28.7	90.9 (±2.7) b	8.3 (±0.2) b	66	72
Pasture	2688	17.9	83 (±12) ab	7 (±0.9) a	71	78	4064	31.5	108.4 (±13.0) b	9.9 (±1.1) b	78	86
Forest	2688	26.4	117 (±10) a	10 (±0.8) a	100	100	4064	36.8	138.3 (±9.4) a	11.5 (±0.7) a	100	100

Different letters in the same columns express a significant difference among treatment at $P < 0.05$ according to Tukey's mean difference significance test. Values in parenthesis represent standard error of $n = 4$ for tilled soils and $n = 3$ for pasture and forest soil.

cultivation may have been greater than that presented in these comparisons. There was some improvement in SOC in pasture as reported previously (Conant et al., 2001), but the beneficial effect of pasture was limited to the surface 15–20 cm of soil (Table 1). Pasture soil had 29 ± 3 Mg ha^{-1} greater SOC in the top 10 cm layer than the cultivated soils. Furthermore, the non-particulate fraction of C was greater under pasture than NT (Franzluebbers and Stuedemann, 2002).

Within the surface 20 cm, results of C and N were very consistent. Below 20 cm, minor differences in N occurred, but treatment effects were similar to SOC. Similar results were reported by Murty et al. (2002).

Change in SOC stock from cropping compared with forest land was less than that reported by Mikhailova et al. (2000) in a Russian Chernozem after 50 years of continuous cultivation and hay production. They observed significant reductions to 100 cm depth with an average loss of 35% for SOC and 55% for N concentration. However, the lack of differences among tillage treatments in SOC and N stocks was similar to observations made previously such as on a Mollisol in the dryland US northern Great Plains (Halvorson et al., 2002), on soils in Alberta, Saskatchewan and eastern Canada (Carter and Rennie, 1982; Angers et al., 1995, 1997), on soils in Illinois (Wander et al., 1998); and in Vertisols in Australia (Mielke et al., 1986; Dalal, 1988). This lack of beneficial effect of NT may have been due to the high initial level of SOC and clay contents, which may have contributed to form very stable and time-resilient soil aggregates. Additional SOM may not be protected within those already highly stable aggregates. This hypothesis refers to the concept of saturation capacity of soil to sequester SOC (Hassink, 1997; Hassink and Whitmore, 1997; Six et al., 2002). The initial SOC concentration seems to be an important parameter towards predicting the magnitude of SOC loss due to cultivation. However, Mann (1986) found that fractional loss of SOC (i.e. difference of SOC between cultivated and uncultivated situation, divided by the initial SOC content) increased with increasing initial SOC concentration. Davidson and Ackerman (1993) did not observe any "initial SOC" effect in their literature survey of SOC changes due to cultivation.

3.4. Comparison of soil organic carbon stock in no till and plow till soils

Several researchers have reported similar SOC stock under NT versus PT even in coarse-textured soils (Powlson and Jenkinson, 1981; Yang and Wander, 1999; Yang and Kay, 2001). Based on the approach of Paustian et al. (1997) who analyzed 27-paired experiments of NT versus PT, we expanded this approach to include the results of 56-paired (including the present study) experimental comparisons of SOC stocks reported for NT and PT treatments (Table 3). Among the 56 pairs, 42 had a positive increase of SOC under NT and 11 had a negative response. Among the 42 pairs with SOC gain, statistically significant differences were reported in only

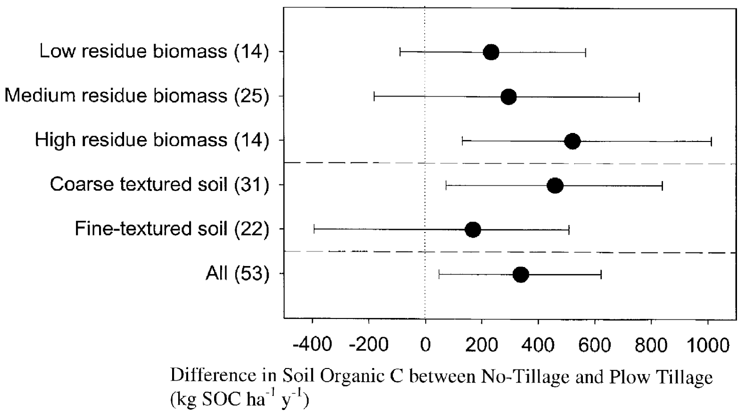

Fig. 5. Soil organic carbon sequestration rate (mean and 95% confidence interval) under NT in response to soil type and intensity of cropping. The number of studies is in parenthesis.

Table 3
References included in the dataset for meta-analysis

Location	Soil type	Crop rotation	Duration of NT (year)	Sampling depth (cm)	Rate of sequestration kg SOC ha^{-1} $year^{-1}$	References
St. Lambert, Que.	Aeric Haplaquept	Silage C	11	24	345	Angers et al. (1995)
Harrington, PEI	Haplorthod	W–B–B–SB	8	60	−995	Angers et al. (1997)
La Pocatière, Que.	Humaquept	C–SB	6	60	−3380	Angers et al. (1997)
Normandin, Que.	Humaquept	C–SB	3	60	900	Angers et al. (1997)
Ottawa, Ont.	Eutrochrept	C	5	60	1196	Angers et al. (1997)
Ottawa, Ont.	Eutrochrept	C–W	5	60	2966	Angers et al. (1997)
Dehli, Ont.	Psamment	C	4	60	−770	Angers et al. (1997)
Harrow, Ont.	Haplaquoll	C	11	60	−85	Angers et al. (1997)
Boigneville, France	Typic Eutrochrep	C	18	Eq 30	139	Balesdent et al. (1990)
Sydney, NB	Pachic Haplustoll	SW	22	20	306	Cambardella and Elliott (1992)
Swift Current SAS	Typic Haploboroll	W–F	12	15	31	Campbell et al. (1999)
Swift Current SAS	Typic Haploboroll	W	12	15	251	Campbell et al. (1999)
Lethbridge, ALB	Typic Boroll	W–F	16	14	−508	Carter and Rennie (1982)
Melfort, SAS	Udic Boroll	W–F	12	20	719	Carter and Rennie (1982)
Watrous, SAS	Typic Boroll	W	4	10	−1052	Carter and Rennie, 1982
Scott, SAS	Typic Boroll	W–W–W–W–2y of oilseeds	2	10	2734	Carter and Rennie (1982)
Warwick, Australia	Udic Pellustert	W or B	14	30	128	Dalal (1988)
Hoytville, OH	Mollic Epiaqualf	C	18	20	333	Dick et al. (1986) recalculated from Lal et al. (1998)
Hoytville, OH	Mollic Epiaqualf	C–SB	18	20	778	Dick et al. (1986) recalculated from Lal et al. (1998)
Crossville, AL	Typic Hapludult	C (W as covercrop)	10	20	1717	Edwards et al. (1992)
Crossville, AL	Typic Hapludult	SB (W as covercrop)	10	20	1138	Edwards et al. (1992)
Crossville, AL	Typic Hapludult	C–SB (W as covercrop)	10	20	441	Edwards et al. (1992)
Horseshoe, GA	Typic Rhodudult	SG–W or SB	6	21	330	Groffman (1984)
Mandan, ND	Typic Haplustoll	SW–F	12	30.4	−225	Halvorson et al. (2002)
Mandan, ND	Typic Haplustoll	SW–WW–Sun	12	30.4	542	Halvorson et al. (2002)
Manhatten, KS	Cumulic Hplustoll	SB	11	15	155	Havlin and Kissel (1997)
Manhatten, KS	Cumulic Hplustoll	SG–SB	11	15	345	Havlin and Kissel (1997)
Manhatten, KS	Cumulic Hplustoll	SG	11	15	109	Havlin and Kissel (1997
Griffin Farm, GA	Typic Kanhapludult	S or SG–WW–rye	17	20	588	Hendricks et al. (1998)
Horseshoe, GA	Rhodic Khanhapludult	S–WW	17	21	353	Hendricks et al. (1998)
Canterbury, New Zealand	Typic Eutrochept	W–P–Cl–RG	9	15	3083	Hermawan and Cameron (1993)
Lexington, KY	Typic Paleudalf	C (RG as covercrop)	20	30	165	Ismail et al. (1994)
Elwood, IL	Aeric Ochraqualf	C	6	30	987	Mielke et al. (1986)
Waseca, MN	Aquic Hapludoll	C	11	15	591	Mielke et al. (1986)

Waseca, MN	Typic Endoaquoll	C	6	30	−3	Mielke et al. (1986)
Lincoln, NB	Pachic Argiustoll	C	6	30	2523	Mielke et al. (1986)
Sydney, NB	Aridic Argiustoll	W–F	12	30	37	Mielke et al. (1986)
Corpus Christi, TX	Typic Orchraqualf	4y Cot–4y C	15	20	347	Potter et al. (1998)
Rothamsted, UK	Batcombe series in UK classification	WW	5	Eq 25	−88	Powlson and Jenkinson (1981)
Boxworth, UK	Hanslope series in UK classification	WW	6	Eq 25	507	Powlson and Jenkinson (1981)
Headley Hall Leed's University, UK	Wothersome series in UK classification	SB	8	Eq 25	270	Powlson and Jenkinson (1981)
Penicuik, Scotland	Macmery series in UK classification	SB	10	Eq 25	−136	Powlson and Jenkinson (1981)
Kellogs, BS, MI	Typic Hapludalf	C–SB–W	9	7.5	333	Robertson et al. (2000)
Sydney, NB	Pachic Haplustoll	WW–F	27	20	193	Six et al. (1999)
Wooster, OH	Typic Fragiudalf	C	34	20	125	Six et al. (1999)
Kellogs, BS, MI	Typic Hapludalf	C–S–W	34	20	63	Six et al. (1999)
Lexington, KY	Typic Paleudalf	C	25	20	247	Six et al. (1999)
Perry, IL	Acquic Argiudoll	C–SB	11	30	327	Wander et al. (1998)
Monmouth, IL	Acquic Hapludoll	C–SB	11	30	991	Wander et al. (1998)
Delkab, IL	Typic Haplaquall	C–SB	11	30	18	Wander et al. (1998)
Guelph, Ont.	Typic Hapludafl	Alf	20	20	263	Yang and Kay (2001)
Columbus, OH Don Scott Exp.	Typic Argiaquoll	C–SB	8	Eq 30	268	This study

C: corn; SB: soybean; WW: winter wheat; SW: spring wheat; F: fallow; B: barley; SG: sorghum; Sun: sunflower; Cot: cotton; Cl: clover; RG: ryegrass; Alf: alfafa, Eq: equivalent soil mass corresponding to this sampling depth under PT.

10 pairs. No studies actually indicated a significant decrease under NT. The increase of SOC stock upon conversion to NT averaged 3.8 Mg ha^{-1} but with large scatter ranging from -20 to $+27$ Mg ha^{-1}. In comparison with the SOC sequestration rates under NT of 300–800 kg C ha^{-1} year^{-1} reported in the literature, (Paustian et al., 1997; Lal et al., 1998; Follett, 2001), we calculated an average rate of 330 kg C ha^{-1} year^{-1} (Figs. 5 and 7). The 95% confidence interval of the sequestration rate was 47–620 kg SOC ha^{-1} year^{-1} suggesting that conversion to NT had an overall positive effect on SOC sequestration (Fig. 5). Significantly positive sequestration rates were observed in coarse-textured soils and in systems with high residue inputs. As pointed out by Franzluebbers and Steiner (2002) climatic factors may be of primary importance in determining the SOC storage capacity in NT.

When SOC stocks in NT were plotted against those in PT (Fig. 6), the increase of SOC stock after conversion to NT was 4.6% of the initial SOC stock under PT with a 95% confidence interval of 1–8%. This coefficient of increase in SOC stock under NT was smaller than the one calculated by West and Post (2002). They concluded that conversion to NT could increase SOC stocks by 16%. Two uncertainties, or sources of error, can be pointed out in our dataset: (i) most of the studies reported stock for the same soil depth, therefore, leading to an overestimation of SOC stock under NT if bulk density was greater under NT; and (ii) few studies accounted for the litter residues in NT, this on the other hand, could lead to an underestimation of SOC stock under NT (Yang and Wander, 1999; Mann et al., 2002). There was no apparent effect of

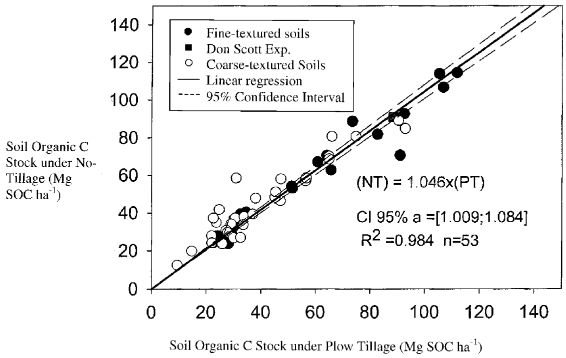

Fig. 6. Soil organic carbon stock under NT plotted against SOC stock under PT. Linear regression plot (sold line) is represented with 95% confidence interval (long dotted line).

texture (as confirmed by the meta-analysis) or of the antecedent SOC stock (i.e., SOC under PT) effect on SOC, as reflected in Fig. 7.

4. Conclusions

Our experimental study did not show a strong positive effect of NT on the overall SOC and N sequestration potential in this Mollisol. However, an increase in SOC concentration in the 0–5 cm soil layer of NT compared with PT was observed. One of the reasons for this lack of difference may have been the short duration of the experiment (e.g., 8 years). However, most of the changes in SOC are likely to occur within the first decade of conversion to NT. The mechanisms and pathways of SOC accrual are proba-

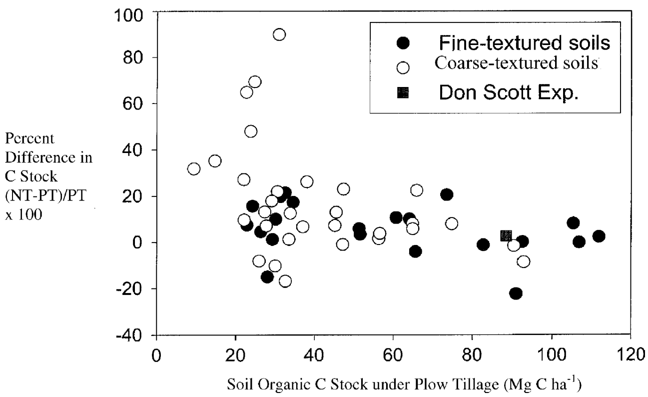

Fig. 7. Percent difference in stock under no till vs. plow till in relationship to SOC stock in plow tilled plots.

bly more complex and more dependent on site-specific pedo-climatic conditions and therefore less universal than simply reversing the trajectory of SOC loss by cultivation. From the literature analysis, we suggest a cautious approach be used to generalize the effect of NT on SOC stock. The magnitudal effect of NT on SOC stock was highly variable. Regardless, the conversion of conventional tillage to minimum or NT can still be promoted as a strategy for minimizing SOC losses during cropping.

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