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Impacts of long-term and recently imposed tillage practices on the vertical distribution of soil organic carbon

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ABSTRACT

Although many studies suggest that no-tillage (NT) increases soil organic carbon (SOC) within the soil profile relative to mouldboard ploughing, other studies indicate that no net change occurs. The latter studies suggest that NT only stratifies the SOC, where a near-surface increase in SOC is offset by a concomitant decrease in the subsurface. We examined the SOC distribution and stocks in a cool, humid Brookston clay (Typic Argiaquoll) soil under four soil management systems with a corn–soybean rotation. The objectives of this study were to compare the profile distribution and total amount of SOC under long-term (21 years) NT and mouldboard plough (MP) tillage with the changes that occur over 8 years when 13-years continuous NT is converted to MP, and when 13-years continuous MP is converted to NT. In the top 5 cm of soil, the long-term NT management accumulated greater SOC compared with the long-term MP treatment. However, this near-surface increase was offset by lower SOC concentrations in the 10–20 cm depth, resulting in similar total amounts of SOC stored in 0–20 cm for both long-term NT and MP. The SOC stratification that existed after 13 years of NT management was eliminated with one mouldboard ploughing operation, however the total SOC content in the plough layer of the new-MP treatment remained relatively constant over the subsequent 8 years. Soil organic carbon stratification was evident in the new no-tillage treatment 3 years after the cessation of tillage. The continuous build-up of SOC in the surface of new-NT soils was associated with no change in the total amount of SOC in the plough layer relative to long-term NT. This implies that the diminution of SOC in the 10–20 cm depth was at the same rate as the accumulation of SOC in the 0–5 cm depth. Although there was no net effect of tillage on total carbon stocks in this fine-textured soil, SOC stratification required several years to build-up after adoption of NT, but only a single year to destroy under MP.

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1. Introduction

The use of continuous no-tillage (NT) in southern Ontario for corn production on fine-textured soils has been limited because it generates wetter and cooler conditions during spring planting, which in turn reduces corn emergence and early corn growth (Fortin and Pierce, 1991; Drury et al., 1999; Dwyer et al., 2000). As a result, some farmers are abandoning continuous NT for corn production, and either reverting back to mouldboard plough (MP) or adopting periodic MP coupled with NT or some other conservation tillage system such as zone tillage (Drury et al., 2003, 2006).

While some studies reported net increases in the total soil organic carbon (SOC) sequestered under NT relative to MP (e.g., Kern and Johnson, 1993; West and Post, 2002), other studies indicated that total SOC was not increased by NT, but "stratified" where an increase in SOC in the near-surface was offset by a corresponding decrease in the subsurface soil layers (Carter and Rennie, 1982; Angers et al., 1995; Paustian et al., 1997; Yang and Wander, 1999; Dolan et al., 2006). Evidence for SOC stratification under continuous NT is provided by an extensive comparison of long-term NT versus long-term MP (374 observations) which showed that NT did not store more carbon than MP, when the SOC stocks were determined for the entire rooting zone in the soil profile (Manley et al., 2005). By comparing carbon accumulation under NT and conventional tillage practices (51 studies, 374 observations), Manley et al. (2005) noted that (1) NT wheat seems to be less effective at sequestering carbon than other crops, and (2) NT in the Southern US was more effective at storing carbon than NT in the Corn Belt area of the United States. In general, SOC stratification under continuous NT with no net SOC accumulation in the plough layer (≈0–20 cm depth) appears to occur primarily in

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humid regions on fine-textured soils that are poorly drained (Carter and Rennie, 1982; Dick et al., 1991; Angers et al., 1995, 1997; Wander et al., 1998; Yang and Wander, 1999; Deen and Kataki, 2003; VandenBygaart and Kay, 2004; Dolan et al., 2006; Yang et al., in press).

Although the impacts of consistent tillage on the amounts and profile distributions of SOC are well documented, our understanding is limited with respect to how SOC responds to sudden changes in tillage, such as replacement of long-term NT by MP, or replacement of long-term MP by NT. For example, McCarty et al. (1998) found that conversion of MP to NT (on a silt loam in Maryland) caused substantial SOC stratification within only 3 years, but no net change in the total amount of SOC present. Stockfisch et al. (1999), on the other hand, found that a single mouldboard ploughing of long-term minimum tillage (20 years) on a silt loam soil in Germany not only removed all evidence of stratification, but also significantly reduced the total amount of SOC accumulated in the plough layer through the minimum tillage. VandenBygaart and Kay (2004) also found that a single ploughing of long-term NT removed the SOC stratification in a sandy loam and a silty clay loam in southern Ontario, Canada, but they did not observe the significant reduction in total SOC stored as did Stockfisch et al. (1999). Quincke et al. (2007) also found that a single ploughing of long-term NT removed SOC stratification, but did not decrease the total SOC storage in the plough layer.

The objectives of this study were to compare the profile distribution and total amount of SOC under long-term (21 years) NT and MP tillage, with the changes which occurred over 8 years when 13-years continuous NT was converted to MP, and when 13-years continuous MP was converted to NT.

2. Materials and methods

This study was conducted on a Brookston clay loam (poorly drained; lacustrine; clayey, mixed, mesic Typic Argiaquoll) located at the Eugene Whelan Research Farm, Agriculture and Agri-Food Canada, Woodslee, Ontario (42°13′N; 82°44′W; mean annual air temperature of 8.9 °C; mean annual precipitation of 876 mm). The average texture in the top 20 cm was 28% wt. sand, 35% wt. silt, and 37% wt. clay.

The study was initiated in 1996 by splitting existing long-term (13 years) MP and NT plots in half to produce two plots 35 m long by 12.2 m wide. One-half of each MP plot was converted into new-NT (NNT) while the remaining half was left intact as long-term MP (LMP). Similarly, one-half of each NT plot was converted to new-MP (NMP) while the remaining half was left intact as long-term NT (LNT). All plots were cropped to continuous corn (*Zea mays* L.) from 1983 to 1996, and in spring 1997 a corn–soybean (*Glycine max* (L.) Merr.) rotation was initiated by planting half of each plot along its length (35 m × 6.1 m) into corn and the other half into soybean. Hence, both crops in the rotation were present each year on all four tillage treatments (LMP, NMP, LNT, NNT). The soil was not disturbed in the two NT treatments except for planting, banding of starter fertilizer, and side-dress application of nitrogen. The two MP treatments consisted of fall mouldboard ploughing (17–20 cm depth), and spring secondary tillage consisting of two passes with a triple-K cultivators pulling harrow and rolling peckers. The tillage treatments were arranged in a randomized complete block design with two replicate plots per treatment.

In late fall or early spring of 1996, 1997, 1999, 2002 and 2004 (between cropping seasons), three to six replicate soil cores (replication varied with year) were collected per plot from the corn phase of the rotation. The cores were collected from the 0–60 cm depth, except in 1997 when the cores were collected from the 0–20 cm depth. The cores (3.3 cm diameter) were obtained using a tractor-mounted Concord soil sampler, fitted with acrylic tubes inserts. The soil filled inserts were transported to the laboratory and then cut into six segments (0–5, 5–10, 10–20, 20–30, 30–40, and 40–50 cm) except for 1997 when the samples were cut into three segments (0–5, 5–10, 10–20 cm). Visibly identifiable crop residues were removed, and gravimetric soil moisture determined by drying subsamples at 105 °C. The bulk density of the samples was calculated using the inner diameter of the core sampler, the segment length, the mass of soil in each segment and the gravimetric moisture content of each segment (Table 1). Total soil carbon content was determined using a Leco CN 2000 analyzer (Leco Corp., St. Joseph, MI) and since the soils were virtually free of carbonates, organic carbon was assumed to equal total carbon.

In order to account for among-treatment differences in bulk density, SOC stocks were determined on an equivalent soil mass basis (Ellert and Bettany, 1995). Briefly, the depth of soil included to determine SOC stock varied according to sample bulk density so that the among-treatment comparisons of SOC were related to the same (equivalent) mass of soil. The soil equivalent masses selected were 750, 1500 and 3000 Mg ha^{-1}, which corresponded to depths of 0–5, 0–10, and 0–20 cm, respectively, in the LNT treatment, but slightly different depths in the other treatments. Equivalent mass was determined by multiplying the bulk density of each core segment by the segment length, and then summing from the soil surface downward.

To minimize annual variations in SOC, ratios of SOC in the following tillage treatment comparisons (LNT/LMP, NMP/LNT, and NNT/LMP) were determined for each equivalent soil mass and year; and these were used to indicate SOC enrichment (i.e. ratio > 1), depletion (ratio < 1) or no change (ratio = 1) for the "numerator" treatment relative to the "denominator" treatment.

Statistical comparisons of SOC total amount (i.e. LNT versus LMP; LNT versus NMP; and LMP versus NNT) were conducted at each measurement time (1996, 1997, 1999, 2002, 2004), and for each equivalent soil mass using a paired *t*-test ($P < 0.05$).

Table 1
Soil bulk density from 1996 to 2004 for long-term NT (LNT), long-term MP (LMP), new NT (NNT), and new MP (NMP)

Depth (cm)	Bulk density (Mg m^{-3})			
	LNT	LMP	NNT	NMP
1996				
0–5	1.14	1.20	–	–
5–10	1.15	1.21	–	–
10–20	1.22	1.21	–	–
1997				
0–5	1.23	1.32	1.30	1.30
5–10	1.45	1.47	1.45	1.47
10–20	1.52	1.45	1.54	1.53
1999				
0–5	1.13	1.38	1.37	1.34
5–10	1.54	1.52	1.57	1.50
10–20	1.52	1.44	1.53	1.54
2002				
0–5	1.11	1.22	1.26	1.24
5–10	1.39	1.42	1.39	1.40
10–20	1.40	1.40	1.38	1.34
2004				
0–5	1.08	1.19	1.14	1.21
5–10	1.27	1.23	1.28	1.22
10–20	1.26	1.21	1.26	1.18

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