Published November 14, 2014

Conventional and No-Tillage Effects on the Distribution of Crop Residues and Light Fraction Organic Matter

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Tillage management on agricultural soils is important because of its effect on soil organic matter (SOM) dynamics. The decomposition of fresh crop residues to stabilized organic matter by soil microbes results in a continuum of intermediary SOM fractions or pools. The light fraction organic matter (LFOM) represents one of the SOM pools formed in the early stages of decomposition and is distinguished as a potential labile SOM pool which is sensitive to changes in management practices. The objective of this study was to measure the quantity, distribution, and δ^{13}C signature of the LFOM pool in farmland soils managed under a conventional tillage (CT) and no-tillage (NT) system. The study uses the δ^{13}C natural abundance technique which involved a crop rotation of C_3 and C_4 species on a calcareous Typic Hapludalf soil. The LFOM was obtained using density fractionation, while the organic C, N, and δ^{13}C of whole soil and light fraction were measured using high-temperature combustion coupled with isotope ratio mass spectrometry. Our findings showed that there was a significant increase in the light fraction C and N pools in the NT soils compared with the CT soils after 6 yr of NT. There was a higher proportion of corn-derived C in the light fraction in the 0- to 10- and 10- to 20-cm depth of NT soils. The differences in the isotopic signature of the whole soil and SOM fractions also show a preservation of newly derived C in the NT soils compared with the CT soils.

Abbreviations: CT, conventional tillage; δ^{13}C, isotopic signature of carbon; LF, light fraction; LFC, light fraction carbon; LFN, light fraction nitrogen; LFOM, light fraction organic matter; NT, no-tillage; SOC, soil organic carbon; SOM, soil organic matter; TN, total nitrogen; TOC, total organic carbon.

Crop residue decomposition by the soil microbial biomass results in organic C being oxidized to CO_2 (and released to the atmosphere) or stabilized as organic matter. However, during the continuum of residue decomposition, a transitory intermediate pool known as "physically uncomplexed organic matter" can be recovered, which consists of organic material not bound to soil minerals (Gregorich and Beare, 2008). Based on the method of separation, the "physically uncomplexed organic matter" is either referred to as particulate organic matter (POM [particle-size fractionation using wet-sieving techniques]) or the light fraction (LF [density fractionation]).

Density fractionation refers to the physical separation of SOM using a liquid of known specific gravity, into a low- and high-density fraction, known as the light and heavy fraction, respectively (Poirier et al., 2005; Sohi et al., 2001; Strickland and Sollins, 1987). The specific gravity of the density-separation liquids typically range from 1.5 to 2.0 g cm^{-3}, which allows for maximum recovery of the LF and minimum contamination from the heavy fraction (Christensen, 1992; Gregorich and Janzen, 1996; Cerli et al., 2012). The two major density-separation liquids

Soil Sci. Soc. Am. J. 79:74–80
doi:10.2136/sssaj2014.05.0182
Received 1 May 2014.
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used are sodium iodide (Bremer et al., 2008; Haile-Mariam et al., 2008; Janzen et al., 1992; Murage et al., 2007; Sohi et al., 2005) and sodium polytungstate (Basile-Doelsch et al., 2009; Golchin et al., 1994; Leifeld and Kögel-Knabner, 2005; Tan et al., 2007).

The LF includes residues in various stages of decay, with high C and low N and ash concentrations (Golchin et al., 1994), but not having undergone complete transformation (Gregorich and Janzen, 1996). Thus, it is a potential labile SOM pool, sensitive to changes in soil and crop management practices, and an important indicator of soil quality (Gregorich et al., 1996; Janzen et al., 1992; Leifeld and Kögel-Knabner, 2005; Simonsson et al., 2014). In comparison, the heavy fraction is composed of highly decomposed, more resistant organic material that is closely associated with soil minerals. It also has a lower C concentration and higher N and ash content than the LF (Gregorich and Janzen, 1996).

This study is composed of two tillage systems: conventional tillage (CT) and no-tillage (NT). In this study, CT refers to primary tillage in the fall with a moldboard plow to a depth of 15 to 20 cm, followed by secondary tillage in the spring with a cultivator. Conventional tillage is defined as any tillage system that results in <15% of crop residues on the soil surface after planting the next crop (Koller, 2003). In NT the soil is undisturbed (no mechanical mixing) except for seeding and fertilizer injection, and crop residues are left on the soil surface.

Conventional tillage increases the decomposition rate of crop residues since it places them into a more favorable environment for microbial decomposers (Angers et al., 1997; Wanniarachchi et al., 1999; Wright and Hons, 2005). The redistribution of plant residues and SOC within the soil profile (Allmaras et al., 2004; Angers et al., 1995) caused by tillage influences microbial activity and biomass, soil temperature, soil water content, soil aeration, soil bulk density, aggregate formation, and nutrient stratification (Cambardella and Elliott, 1993). Crop residues incorporated into the soil are less subjected to extremes in temperature and moisture compared with residues left on the soil surface.

In the NT soils, crop residues are left on the soil surface, thus changes in C concentrations are more apparent with depth in the soil profile (Halpern et al., 2010). Studies have reported increased SOM levels in the surface layers of soil under NT management (Blevins et al., 1983; Lal et al., 1999; West and Post, 2002). However, other studies have shown that NT causes no change in total SOC in the profile but stratification of SOC, where increases in surface layers are offset by decreases in subsurface layers (Baker et al., 2007; Yang et al., 2008).

In this study, the isotopic signature ($\delta^{13}C$) of the LF was determined using the ^{13}C natural abundance technique. This technique utilizes the difference in $\delta^{13}C$ values of C_3 and C_4 plants to identify the source, pools, and fate of organic C in soils (Balesdent et al., 1987). Soils developed under C_3 or C_4 vegetation contain SOM with $\delta^{13}C$ of -27 or -13‰, respectively. This contrast in isotopic signature of plant residues is maintained throughout the continuum of decomposition processes and transferred to residue-derived stable SOM pool. When the residues and soil have different isotopic signatures, a two-source mixing model can be used to quantify the C derived from each component (Balesdent et al., 1987). For our research, corn (*Zea mays* L.) was used as the C_4 tracer material, while soybean [*Glycine max* (L.) Merr.] and wheat (*Triticum aestivum* L.) provided a source of C_3 residues.

The objective of this study was to measure the quantity, distribution, and $\delta^{13}C$ signature of the LFOM pool in farmland soils managed under a CT and NT system. We also investigated the effect of tillage practices on the distribution of C_4 and C_3–derived carbon in the LF.

MATERIAL AND METHODS

Study Site

This study was performed at the Elora Research Station (43°38′ N, 80°25′ W), about 20 km northwest of Guelph, southern Ontario, Canada. The soil is a Typic Hapludalf (gray-brown Luvisol) derived from calcareous glacial till parent material. The soil is a silt loam (sand 270 g kg^{-1}, silt 560 g kg^{-1}, clay 170 g kg^{-1}) with an average pH of 7.3, total N of 1.8 g kg^{-1}, and TOC of 21.2 g kg^{-1} in the top 0- to 20-cm soil layer. The site receives a mean annual precipitation of 900 mm, and average monthly temperature ranges from −7.1°C in January to 19.8°C in July.

The research site consisted of four large-scale plots (2 CT and 2 NT), each 100 by 150 m (1.5 ha). Each plot was divided into six subplots (50 by 50 m), of which four were selected for soil and plant sampling. All plots were initially managed under CT, but beginning in the year 2000, two of the plots were converted to NT. From 2000, the site was planted with either a C_3 or C_4 crop in an annual rotation. Corn was grown in 2000, 2003, and 2005, winter wheat in 2002, and soybean in 2001 and 2005. This study was performed from fall 2005 to fall 2006, at which time corn and soybean were grown, respectively. Historical data show that corn was first grown in 1969 in rotation with alfalfa, winter wheat, barley, and soybean. The control ^{13}C site was a native forest soil located adjacent to our research site. With the exception of tillage management, agronomic practices were identical for all the plots.

Soil Sampling and Preparation

Soil sampling was performed in October 2005 (after corn harvest) using a hydraulic core sampler (38 mm i.d.) to obtain the top 0- to 30-cm soil layer. The plant spacing for corn was 75 cm between rows and 20 cm within the rows. Within the subplots, four cores were collected at four locations relative to the corn plant (spacing 75 by 25 cm): on the plant, midway between plant within the rows, quarter way (1/4), and halfway (1/2) between plant rows. Each soil core was divided into depth increments of 0 to 10, 10 to 20, and 20 to 30 cm.

Soil samples at field moisture content were gently hand crushed, and visible crop residues were removed by handpicking before passing the soil through a 2-mm sieve to obtain the fine-earth fraction used for soil analyses. In this study, the LF organic matter is a fraction that was specifically measured after a soil has been passed through a 2-mm sieve, which would have an effect on the amount recovered. The plant material >2 mm and hand-picked crop residues collected were retained and separated into two groups (litter and roots) for analysis. Soil moisture content was obtained by drying a 10-g subsample of the soil at 105°C for 24 h. Root- and residue-free soil samples were then stored at 4°C until chemical analyses.

Isolation of Light Fraction by Density Fractionation

Light fraction organic matter was isolated from the soil using density fractionation (Gregorich and Beare, 2008). A 30-g sample of soil was placed into a 250-mL centrifuge bottle (polypropylene, wide mouth) and 100 mL of sodium iodide (NaI) solution was added. Based on studies on similar agricultural soils in Canada (Janzen et al., 1992; Wanniarachchi, 1997; Soon et al., 2007), the specific gravity of the NaI solution used was 1.7, as determined with a precision hydrometer (Thomas Scientific, Swedesboro, NJ). This minimizes contamination of the LF with organomineral particles, which can have densities of 1.7 to 2.0 g cm^{-3} (Janzen et al., 1992). The bottles were capped, placed upright, and shaken on an end-to-end platform shaker for 1 h at 160 rpm. The suspension was allowed to settle for 48 h at room temperature.

The particulate LF floating on the surface of the NaI solution was recovered using a water-jet vacuum filtration system. The vacuum filtration system (aspiration unit) consisted of a 300-mL, 47-mm magnetic filter funnel (Pall Corporation, East Hills, NY) fitted with a 0.45 mm–nylon membrane filter (Whatman International, Maidstone, UK) and attached to a 1-L side-arm conical flask using 8-mm (i.d.) Tygon tubing and a 2-mL pipette tip cut at an angle of 45°. The LF was washed using 100 mL of 0.01 M $CaCl_2$ (reduces clogging of filter) followed by 100 mL of distilled water, and then transferred into a Pyrex Petri-dish. The LF was dried at 60°C for 16 h, weighed, and then ground (<250 mm) using an agate mortar and pestle. The samples were analyzed for C, N, and $\delta^{13}C$ using isotope ratio mass spectrometry.

Estimation of Corn-Derived Carbon in the Light Fraction

The proportion of C derived from corn (f_{C4}) inputs in the LF was estimated using a two-end member mixing model (Balesdent et al., 1987):

$$\delta^{13}C_{LF} = f_{C4\text{-}LF} \times \delta^{13}C_{corn} + (1 - f_{C4\text{-}LF}) \times \delta^{13}C_{C3\text{-}LF}$$

Rearranging the equation gives:

$$f_{C4\text{-}LF} = (\delta^{13}C_{LF} - \delta^{13}C_{C3\text{-}LF})/(\delta^{13}C_{corn} - \delta^{13}C_{C3\text{-}LF})$$

where $f_{C4\text{-}LF}$ is the proportion of corn-derived C in the LF, $\delta^{13}C_{LF}$ is the $\delta^{13}C$ of the LF, $\delta^{13}C_{corn}$ is the mean $\delta^{13}C$ of corn residues (-12.2‰ for CT and NT soils), and $\delta^{13}C_{C3\text{-}LF}$ is the average $\delta^{13}C$ of the corresponding LF from uncultivated soil. The $\delta^{13}C$ of the LF for a native forest soil located adjacent to the research site was obtained from a comparable study reported by Wanniarachchi (1997). The $\delta^{13}C$ values of the LF in the native soil were -27.4, -26.9, and -27.1‰ for the 0- to 10-, 10- to 20-, and 20- and 30-cm soil depths, respectively.

Isotopic Analyses

Before isotopic analysis, acid fumigation as described by Ramnarine et al. (2011) was used to remove carbonates which can confound measurements of $\delta^{13}C$ in SOM. Homogenized soil and plant samples for isotopic analysis were placed into 8 by 5 mm tin capsules, with soil sample weights ranging from 20 to 60 mg depending on organic C concentration, while 1 mg was sufficient for corn and soybean plant samples. These sample weights provided the amount, about 420 mg of organic C, required for mass spectrometer analysis. The tin capsules with samples were carefully sealed (to prevent leakage), compressed (to remove trapped CO_2), and arranged in a 96-well microtiter plate.

Soil and plant samples were analyzed at the Stable Isotope Laboratory, University of Saskatchewan, Saskatoon, Saskatchewan, Canada. Carbon, N, and $\delta^{13}C$ were simultaneously determined by continuous flow isotope ratio mass spectrometry (CF-IRMS) using an ANCA-GSL elemental analyzer (EA) coupled to a Tracermass spectrometer (Europa Scientific, Crewe, UK). The stable carbon isotope ratio was expressed as $\delta^{13}C$ in per mil (‰) units and calculated as $\delta^{13}C$ (‰) = $[(R_{sample}/R_{standard} - 1] \times 1000$, where R_{sample} and $R_{standard}$ is the $^{13}C/^{12}C$ ratio of the sample and standard, respectively. The international standard PeeDee Belemnite with an isotope ratio (R) of 0.0112372 was used as the reference, and the precision of $\delta^{13}C$ measurements was <0.1‰.

Statistical Analyses

The experiment was conducted as a split-split plot design, with tillage as the main plot, sampling location relative to the corn plant as the split plot, and depth increment as the split-split plot. The statistical software used was SAS 9.1 (SAS Institute, Cary, NC). Data were tested for normality using the Shapiro–Wilk test and evaluated by analysis of variance (ANOVA) using proc GLM. Proc Mixed was used to obtain the least square means. Least significant differences at $P < 0.05$ were used to determine significant differences between treatment means.

RESULTS

Quantity and Distribution of Light Fraction

The amount of LF in the 0- to 10-cm layer of the no-tillage soils was significantly higher than that of the conventional till soils ($P < 0.001$). For the 0- to 10-cm layer, the CT soil contained 4.2 g LF kg^{-1} soil, whereas the NT soil contained 5.8 g LF kg^{-1} soil (37% higher than the CT soils). For the 10- to 20-cm layer, there was no significant difference, with CT and NT soils having 3.4 g LF kg^{-1} soil and 3.6 g LF kg^{-1} soil, respectively (P = 0.275). Conventional tillage and NT soils had identical quantity of LF in the 20- to 30-cm layer (2.1 g LF kg^{-1} soil). There is a decreasing trend in LF with depth in both tillage treatments. In terms of mass, the LF represents a small percentage (0.2 to 0.6%) of the whole soil dry weight for CT and NT treatments.

Carbon and Nitrogen Concentrations in Light Fraction Versus Whole Soil

Organic C concentrations (whole soil) in the 0- to 10-cm layer of the NT soils (24.1 g C kg^{-1}) were significantly higher than that of the CT soils (21.0 g C kg^{-1}). For the lower depths there were no significant differences in C between tillage treatments (Table 1). The C concentration for the LF was not significantly different for any of the sampling depths between tillage treatments, with values ranging from 250 to 290 g C kg^{-1} LF (Table 1). The light fraction N (LFN) concentration was similar between treatments, ranging from 12 to 15 g N kg^{-1} LF. The C to N ratio of the LF was between 18 and 22 for CT and NT soils, respectively.

Contributions of Carbon and Nitrogen by Soil Organic Matter Fractions

Total organic C and N contents of the whole soil in the 0- to 30-cm depth in CT and NT soils was not significantly different after 6 yr (Table 2). However, the 0- to 10-cm depth of the NT soils had about 10% more SOC than the CT soils. The quantity of C and N in the LF organic matter was significantly higher in the NT soils compared with the CT soils for the 0- to 10-cm layer (Table 2). There were no significant differences in LFC and LFN for the 10- to 20- and 20- to 30-cm depths between tillage treatments.

Table 1. Organic C and N concentrations of the whole soil and light fraction (LF) in conventional tillage and no-tillage treatments at fall 2005 sampling.

Element and soil depth	Conventional tillage	No-tillage	LSD†	*P* value‡
cm	—— g C or N kg^{-1} soil ——			
0–10				
C	21.04 (0.81)§	24.11 (0.52)	1.92	0.002
N	1.68 (0.07)	1.90 (0.06)	0.15	0.007
C/N	12.52 (0.03)	12.70 (0.02)	0.07	<0.001
10–20				
C	19.70 (0.69)	18.65 (0.18)	1.43	0.147
N	1.59 (0.05)	1.50 (0.04)	0.11	0.115
C/N	12.38 (0.04)	12.42 (0.02)	0.08	0.295
20–30				
C	12.60 (0.85)	12.09 (0.14)	1.72	0.556
N	1.06 (0.07)	1.01 (0.03)	0.15	0.473
C/N	11.89 (0.08)	11.97 (0.02)	0.17	0.335
	—— g C or N kg^{-1} LF ——			
0–10				
C	250.5 (5.4)	255.0 (5.7)	15.7	0.567
N	13.8 (0.4)	12.6 (0.4)	1.1	0.029
C/N	18.3 (0.3)	20.5 (0.5)	1.2	<0.001
10–20				
C	277.4 (5.8)	289.4 (5.0)	15.2	0.120
N	14.6 (0.3)	14.3 (0.3)	0.9	0.457
C/N	19.1 (0.4)	20.5 (0.4)	1.2	0.021
20–30				
C	265.7 (7.3)	285.0 (6.7)	19.8	0.057
N	13.2 (0.5)	13.1 (0.4)	1.2	0.912
C/N	20.5 (0.5)	22.0 (0.5)	1.3	0.019

† Least significant difference calculated between two means at $P = 0.05$.
‡ Probability level for the *F* value for tillage effect in ANOVA.
§ Numbers in parentheses are the standard errors of the means ($n = 32$).

Proportion of Light Fraction Carbon to Total Organic Carbon and Light Fraction Nitrogen to Total Nitrogen in Soil

The proportion of light fraction C to TOC (LFC/TOC) in the 0- to 10- and 10- to 20-cm depths of the NT soils was significantly higher than that of the CT soils (Table 3). There was no significant difference in the LFC/TOC between tillage treatments for the 20- to 30-cm depth. The proportion of LFN/TN was not significantly different between treatments for any soil depths (Table 3). Both CT and NT soils showed a decreasing trend in LFN/TN with depth.

$\delta^{13}C$ of Light Fraction Versus Total Organic Carbon

The $\delta^{13}C$ of the total organic C (referred to as TOC–$\delta^{13}C$) in the 0- to 10-cm depth of NT soils was significantly higher (^{13}C-enriched) than that of the CT soils (Table 4). There were no significant differences in TOC–$\delta^{13}C$ for the lower soil depths between tillage treatments. Both CT and NT soils showed a decreasing trend in TOC–$\delta^{13}C$ with depth. The TOC–$\delta^{13}C$ for the CT soils was -23.4, -23.5, and -25.4‰ for the depths of 0 to

Table 2. Organic C and N content of whole soil and light fraction (LF) in conventional tillage and no-tillage treatments at fall 2005 sampling.

Element and soil depth	Conventional tillage	No-tillage	LSD†	*P* value‡
cm	—— C or N (g m^{-2} soil) ——			
0–10				
C	2838 (138)§	3134 (60)	301	0.054
N	227 (11)	247 (5)	24	0.099
0–20				
C	5626 (252)	5736 (68)	521	0.673
N	451 (20)	456 (5)	41	0.818
0–30				
C	7544 (297)	7526 (79)	615	0.954
N	613 (23)	606 (7)	48	0.770
	—— LFC or N (g m^{-2} soil) ——			
0–10				
C	138.8 (4.6)	193.4 (5.6)	14.4	<0.001
N	7.7 (0.3)	9.6 (0.4)	1.0	<0.001
10–20				
C	132.1 (4.2)	146.1 (6.6)	5.6	0.079
N	6.9 (0.2)	7.3 (0.4)	0.8	0.451
20–30				
C	83.3 (2.8)	89.2 (4.3)	10.4	0.264
N	4.2 (0.2)	4.1 (0.2)	0.6	0.815
0–30				
C	354.3 (8.9)	428.7 (11.0)	28.4	<0.001
N	18.8 (0.5)	21.0 (0.7)	1.7	0.014

† Least significant difference calculated between two means at $P = 0.05$.
‡ Probability level for the *F* value for tillage effect in ANOVA.
§ Numbers in parentheses are the standard errors of the means ($n = 32$).

10, 10 to 20, and 20 to 30 cm, respectively. The TOC–δ^{13}C for NT soils was -20.6, -23.6, and -25.2‰ for the depths of 0 to 10, 10 to 20, and 20 to 30 cm, respectively.

The δ^{13}C of the light fraction C (referred to as LF–δ^{13}C) in the 0- to 10- and 10- to 20-cm depths of the NT soils was significantly higher than that of the CT soils (Table 4). There was no significant difference in LF–δ^{13}C for the 20- to 30-cm depth between tillage treatments. The LF–δ^{13}C for the CT soils was -18.3‰ for the 0- to 10-cm depth and -19.3‰ for the 10- to 20- and 20- to 30-cm depths. The LF–δ^{13}C for the NT soils was -16.7, -18.3, and -19.4‰ for the depths of 0 to 10, 10 to 20, and 20 to 30 cm, respectively.

Corn-Derived Carbon in Light Fraction

The proportion of corn-derived C in the light fraction ($^{f}{}_{C4-LF}$) was significantly higher in the 0- to 10-cm ($P < 0.001$) and 10- to 20-cm ($P = 0.003$) depths of the NT soils versus the CT soils. There was no significant difference in $^{f}{}_{C4-LF}$ for the 20- to 30-cm depth between tillage treatments ($P = 0.902$). The $^{f}{}_{C4-LF}$ for the CT soils was 60% for the 0- to 10-cm depth and 52% for the 10- to 20- and 20- to 30-cm depths. The $^{f}{}_{C4-LF}$ for NT soils was 70, 58, and 52% for the depths of 0 to 10, 10 to 20, and 20 to 30 cm, respectively.

DISCUSSION

Quantity and Distribution of Light Fraction

The LFOM tends to decompose more quickly than the heavy fraction, which is more chemically complex and therefore inherently more resistant to microbial degradation (Gregorich and Janzen, 1996). After 6 yr of NT, the LF in the 0- to 10-cm layer of the NT soils was about 40% higher than that of the CT soils. In NT systems, crop residues are left on the soil surface; therefore, it is expected that more LF will be recovered in the topmost depth of a NT soil. Several studies agree with these results where LF is reduced with aggregate disruption by tillage or change in land use (Bonde et al., 1992; Dou and Hons, 2006; Gregorich et al., 1989; Janzen et al., 1992; Larney et al., 1997; Liang et al., 2003; Soon et al., 2007; Whalen et al., 2000). Tan et al. (2007) reported that NT for 27 yr preserved 94% more LF than CT in a silty loam in Ohio. Dou et al. (2008) reported a significant increase in the size of all labile SOC pools in the 0- to 5-cm depth of NT compared with CT for a silty clay loam in south central Texas. Soon et al. (2007) found LF was 22% higher in the 0- to 15-cm depth of NT versus CT plots after 12 yr of NT in a sandy loam soil in northwestern Alberta.

The method used to obtain the LF in this study would have affected the amount of LF obtained. During the soil preparation phase, all visible plant (roots and litter) and animal (earthworms) fragments that would have otherwise been recovered as LF were removed before sieving. The density fractionation procedure used (Gregorich and Beare, 2008) does not entail the disruption of aggregates by sonification as described by Sohi et al. (2001). When aggregates are disrupted, an additional fraction, referred to as the "occluded LF" (Kölbl and Kögel-Knabner, 2004; Wagai et al., 2009; Wander and Yang, 2000; Yang and Kay, 2001) or "intra-aggregate fraction" (Beare et al., 1994; Bossuyt et al., 2002; Sohi et al., 2005), is obtained in addition to the "free" LF.

Table 3. Proportion of light fraction C (LFC) to total organic carbon (TOC), and light fraction N (LFN) to total N (TN) in conventional tillage and no-tillage soils.

Soil depth	Conventional tillage	No-tillage	LSD†	*P* value‡
cm	LFC/TOC (%)			
0–10	5.12 (0.21)§	6.18 (0.14)	0.49	<0.001
10–20	4.87 (0.15)	5.61 (0.23)	0.56	0.011
20–30	4.88 (0.33)	5.03 (0.26)	0.83	0.717
	LFN/TN (%)			
0–10	3.57 (0.14)	3.87 (0.12)	0.37	0.114
10–20	3.20 (0.08)	3.43 (0.16)	0.36	0.227
20–30	2.94 (0.22)	2.72 (0.13)	0.52	0.403

† Least significant difference calculated between two means at $P = 0.05$.
‡ Probability level for the *F* value for tillage effect in ANOVA.
§ Numbers in parentheses are the standard errors of the means ($n = 32$).

The results of our study were similar to that of previous research on Canadian soils. Soon et al. (2007) reported 10 g LF kg^{-1} soil and 12 g LF kg^{-1} soil (NaI, 1.7 g cm^{-3}) for CT and NT soils, respectively, in a sandy loam soil in northwestern Alberta. Murage (2004) findings ranged from 1 to 12 g LF kg^{-1} soil for soils in southern Ontario (NaI, 1.8 g cm^{-3}). Previously, Wanniarachchi (1997) recovered 1 to 3 g LF kg^{-1} soil on the same site (NaI, 1.7 g cm^{-3}). Janzen et al. (1992) reported LF (NaI, 1.7 g cm^{-3}) of 2.5 to 30 g LF kg^{-1} soil from soils with textures ranging from silty clay loams to heavy clays in Saskatchewan.

Carbon and Nitrogen Concentrations in Soli Organic Matter Fractions

The higher organic C concentrations found in the top 0- to 10-cm layer in the NT plots is consistent with findings from other tillage studies. Increases in C concentrations in surface soils of NT have been reported in several studies (Lal et al., 1999; Murage et al., 2007; West and Post, 2002; Yang et al., 2008). Since the LF material represents a continuum of states of residue decay, its C to N ratio is normally between that of fresh plant material and that of the whole soil (Gregorich and Janzen, 1996). The C concentration of 25 to 29% falls in the range (20–30%) typical for LF derived from cultivated soils (Biederbeck et al.,

Table 4. δ^{13}C values of total organic carbon (TOC) and light fraction (LF) in conventional tillage and no-tillage soils at fall 2005 sampling.

Soil depth	Conventional tillage	No-tillage	LSD†	*P* value‡
cm	TOC–δ^{13}C (‰)			
0–10	-23.41 (0.11)§	-20.61 (0.07)	0.25	<0.001
10–20	-23.50 (0.09)	-23.64 (0.05)	0.21	0.219
20–30	-25.41 (0.14)	-25.18 (0.07)	0.32	0.153
	LF–δ^{13}C (‰)			
0–10	-18.29 (0.29)	-16.71 (0.26)	0.77	<0.001
10–20	-19.31 (0.24)	-18.33 (0.20)	0.62	0.003
20–30	-19.31 (0.28)	-19.35 (0.25)	0.75	0.931

† Least significant difference calculated between two means at $P = 0.05$.
‡ Probability level for the *F* value for tillage effect in ANOVA.
§ Numbers in parentheses are the standard errors of the means (n= 32).

1994; Gregorich and Janzen, 1996). Soon et al. (2007) also reported LFC concentrations ranging from 213 to 255 g C kg^{-1} for sandy loam soils in northwestern Alberta. The N concentration of 1.2 to 1.5% is also similar to those of other studies (Janzen et al., 1992; Tan et al., 2007). Our study confirms previous observations that CT can enhance the loss of C from recently added crop residues and LFOM. Conventional tillage increases the decomposition rate of crop residues since it breaks apart soil aggregates and places substrates in closer proximity to microbial decomposers (Angers et al., 1997; Wanniarachchi et al., 1999; Allmaras et al., 2004; Wright and Hons 2005). Our study also supports previous research which indicated that NT has the potential to sequester CO_2 from the atmosphere and reduce CO_2 emissions, based on its ability to protect and stabilize organic matter against decomposition (Gregorich and Janzen, 1996; West and Post, 2002).

Contributions of Carbon and Nitrogen by Soil Organic Matter Fractions

Significantly lower C in the LF of the CT soils can indicate the sensitivity of the LF organic matter to tillage practices. Results show that NT soils contain more C and N in the LF organic matter, which may indicate a higher protective capacity of this form of organic matter at least in the short term. Results of this study were similar to those of other researchers, where significant differences in LFC were reported in the upper soil depth between tillage treatments. Liang et al. (2003) reported that tillage had little effect on LFC in brown and dark brown Chernozems, but significantly decreased LFC in the Black Chernozems in Saskatchewan. Cookson et al. (2008) also found that LFC and LFN were significantly greater in the 0- to 5-cm depth of NT versus CT coarse-textured soils in western Australia. Zotarelli et al. (2007) reported that LFC was significantly higher in the 0- to 5-cm depth of NT soils versus CT soils, but there was no difference in the 5- to 20-cm depth in Oxisols of southern Brazil.

Proportion of Light Fraction Carbon to Total Organic Carbon and Light Fraction Nitrogen to Total Nitrogen in Soil

The proportion of LFC/TOC can range from 2 to 17.5% for surface soils based on a comprehensive study on three long-term crop rotation studies in Saskatchewan, Canada (Janzen et al., 1992). Other studies have reported similar values in the proportion of LFC/TOC in cultivated soils. Bhogal et al. (2009) reported that LFC comprised 3 to 12% of the SOC for nonsieved soils from seven experimental sites in the UK, receiving different levels of organic C additions. Haile-Mariam et al. (2008) found that LFC comprised 3 to 5% of the SOC, with no significant difference between CT and NT treatments, from long-term research sites in the Corn Belt region of the United States. Zotarelli et al. (2007) stated that LFC accounted for 4 and 6% of the TOC for CT and NT soils, respectively, from Oxisols in Passo Fundo, Brazil.

Isotopic Signature of Light Fraction

Isotopic analysis showed that a significantly higher amount of the newly derived C was found in the LF organic matter of NT soils, indicating that CT may promote a loss of C. The significantly higher proportion of corn-derived C in the LF of NT soils in the top 0- to 20-cm soil layer suggests that NT contributes to a preservation of recently added C to the SOM pool (Six et al., 2002). The ^{13}C natural abundance technique was important in understanding the effects of tillage management on the transformation of crop residues to SOM. The study indicates that NT can enhance transformation of crop residue C to soil organic C, thus improving soil fertility and promoting soil C storage in agricultural soils by increasing the LF pool, an important indicator of soil quality (Sequeira and Alley, 2011; Mikha et al., 2013).

CONCLUSIONS

This study showed significant increases in the light fraction C and N pools in the NT soils compared with the CT soils after 6 yr of NT. There was a higher proportion of corn-derived C in the light fraction in the 0- to 10- and 10- to 20-cm depth of NT soils. No-tillage effects are more apparent in the surface soils with the light and heavy fraction being similar at the 20- to 30-cm depth. Differences in the isotopic signature of the whole soil and SOM fractions show a preservation of newly derived C in the NT soils compared with the CT soils.

ACKNOWLEDGMENTS

The authors thank Mr. Myles Stocki who conducted the isotopic analyses. The funding for this research was provided by the Natural Sciences and Engineering Research Council (NSERC) strategic grants program.

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