# Soil organic carbon and nitrogen pools as affected by compost applications to a sandy-loam soil in Quebec

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Whalen, J. K., Benslim, H., Jiao, Y. and Sey, B. K. 2008. Soil organic carbon and nitrogen pools as affected by compost applications to a sandy-loam soil in Quebec. Can. J. Soil Sci. 88: 443–450. Compost contributes plant-available nutrients for crop production and adds partially decomposed carbon (C) to the soil organic carbon (SOC) pool. The effect of compost applications and other agricultural practices on SOC and total nitrogen (N) pools was determined in a sandy-loam Humic Gleysol at the Research Farm of McGill University, Ste-Anne-de-Bellevue, Quebec. Experimental plots with continuous silage corn (*Zea mays* L.) and silage corn-soybean (*Glycine max* L. Merr.) production were under conventional tillage (CT) or no-tillage (NT) management. Composted cattle manure was applied each spring at rates of 0, 5, 10 and 15 Mg (dry weight) ha<sup>-1</sup> and supplemental NPK fertilizers were added to meet crop requirements. The C input from crop residues was affected by tillage, crop rotations and compost application, but differences in the SOC and total N pools were due to compost applications. After 5 yr, compost-amended plots gained 1.35 to 2.02 Mg C ha<sup>-1</sup> yr<sup>-1</sup> in the SOC pool and 0.18 to 0.24 Mg N ha<sup>-1</sup> yr<sup>-1</sup> in the total N pool, as compared with initial pool sizes when the experiment was initiated. These gains in SOC and total N were achieved with agronomic rates of compost and supplemental NPK fertilizers, selected to match the phosphorus requirements of silage corn. Such judicious use of compost has the potential to increase the SOC and total N pools in agroecosystems under annual crop production.

Key words: Composted cattle manure, corn silage, mineral fertilizer, plant-available nitrogen, soil organic carbon

Whalen, J. K., Benslim, H., Jiao, Y. et Sey, B. K. 2008. Incidence du compost sur les réserves de carbone et d'azote dans un sol sableux-loameux du Québec. Can. J. Soil Sci. 88: 443–450. Le compost ajoute aux éléments nutritifs qu'absorbent les plantes cultivées et enrichit le réservoir de carbone organique du sol (COS) avec du carbone (C) partiellement décomposé. Les auteurs ont examiné les effets des applications de compost et d'autres pratiques agricoles sur les réserves de COS et d'azote (N) total dans un gleysol humique sableux-loameux à la ferme expérimentale de l'Université McGill, à Sainte-Anne-de-Bellevue, au Québec. Ils ont utilisé pour cela des parcelles expérimentales consacrées à la monoculture du maïs d'ensilage (*Zea mays* L.) et à un assolement de maïs d'ensilage et de soja (*Glycine max* L. Merr.), avec travail ordinaire ou non-travail du sol. Ils ont appliqué 0, 5, 10 ou 15 Mg (poids sec) de fumier de bovin composté par hectare aux parcelles, qu'ils ont bonifiées avec un engrais NPK, pour satisfaire aux besoins de la culture. Le travail du sol, l'assolement et l'application de compost modifient l'apport de C, mais les variations du réservoir de COS et de N total résultent du compost. Au bout de cinq ans, la réserve de COS des parcelles amendées avec du compost avait augmenté de 1,35 à 2,02 Mg de C par hectare et par année, tandis que celle de N total avait gagné 0,18 à 0,24 Mg de N par hectare et par année, comparativement aux valeurs initiales, au début de l'expérience. Ces gains ont été réalisés avec l'application du taux de compost recommandé par les agronomes et l'addition d'un supplément d'engrais NPK, selon les besoins en phosphore du maïs d'ensilage. Un usage judicieux du compost pourrait accroître la réserve de COS et de N total dans les écosystèmes agricoles des cultures annuelles.

Mots clés: Fumier de bovin composté, ensilage de maïs, engrais minéral, azote assimilable par les plantes, carbone organique du sol

Agricultural practices that conserve soil organic carbon (SOC) are expected to improve the structural stability, nutrient supply and biological activity of agricultural soils. Applying organic fertilizers such as composted animal manure (compost) may help to preserve SOC in agroecosystems. Compost provides plant-available nutrients that can improve crop production, thus increasing the C input from plant residues; plus, compost contains C that can be stabilized and retained in soils (Christopher and Lal 2007). In barley agroecosystems receiving stockpiled cattle feedlot manure for 25 yr, Hao et al.

(2003) reported an increase in SOC concentration in surface soils (0–15 cm) of 0.181 g SOC kg<sup>-1</sup> per 1 Mg ha<sup>-1</sup> of manure C added. Manure applications also increased the total N content, as well as the NO<sub>3</sub>-N

Abbreviations: CT, conventional tillage; DOC, dissolved organic carbon; HF, heavy fraction; LF, light fraction; MBC, microbial biomass carbon; MBN, microbial biomass nitrogen; NT, no-tillage; SOC, soil organic carbon concentration in the soil profile (Hao et al. 2003). In Michigan, corn agroecosystems receiving composted cattle manure (mixed with oak leaves) for 6 yr had 17% more SOC than those receiving inorganic N fertilizer, and there was more N immobilization in soils amended with compost (Fortuna et al. 2003). Vanden-Bygaart et al. (2003) reported that animal manure generally increased the SOC, but did not estimate the increase in SOC due to manuring because varying types and rates of manure were applied in the studies they reviewed. Christopher and Lal (2007) estimated that applying manure plus inorganic fertilizer to cropland in eastern Canada would increase the SOC by 50–150 kg C ha<sup>-1</sup> yr<sup>-1</sup>. This estimate still needs to be validated with field data.

The SOC and N reserves in soils are affected by other agricultural practices, such as tillage and crop rotations. A meta-analysis of long-term experiments in Canada by VandenBygaart et al. (2003) revealed that the SOC was 7.3% ( $\pm$ 2.6) less in conventionally tilled (CT) than in no-till (NT) soils in Western Canada, probably due to faster decomposition of SOC in tilled than NT soils. Yet, SOC levels were virtually the same (-0.1% + 5.0) in CT and NT soils in eastern Canada (VandenBygaart et al. 2003). We propose that SOC and N reserves in compostamended soils would be unaffected by tillage in eastern Canada, but we are not aware of data that would support or refute this hypothesis. Crop rotations also affect the SOC; two Ontario studies (Gregorich et al. 2001; Yang and Kay 2001) showed that crop rotations (legumes in rotation with corn) increased the SOC by 13.4% ( $\pm$ 9.8), compared with a corn monoculture (VandenBygaart et al. 2003). In Quebec, the annual C and N inputs were greater in a barley-forage (red clover and timothy) rotation than barley monoculture, which increased in SOC and N contents in a silty clay Humic Gleysol (Bissonnette et al. 2001). The management systems that increased SOC and N contents above initial levels were: (1) barley-forage rotation receiving liquid dairy manure, tilled with a moldboard plow, (2) barleyforage rotation receiving inorganic fertilizer, chisel plowed, and (3) barley-forage rotation receiving liquid dairy manure, chisel plowed (Bissonnette et al. 2001). There may be an interactive effect of tillage practices and crop rotations on the SOC and N reserves in compostamended soils, but this remains to be confirmed.

The objective of this study was to evaluate how 5 yr of composted cattle manure applications changed the SOC and N in a sandy-loam soil in Quebec, as well as the effects of tillage and crop rotations on SOC and N in this soil.

# MATERIALS AND METHODS

The study site was located on the Macdonald Research Farm, Ste. Anne de Bellevue, Québec (lat. 45°28'N, long. 73°45'W). Annual temperature at the nearby Pierre Elliott Trudeau International Airport (Dorval, Quebec) averages 6.1°C, with mean annual precipitation of 967 mm (Environment Canada 2004). The soil, a Humic Gleysol (fine, mixed, frigid Typic Endoaquent), contained a sandy-loam layer (mean thickness 28 cm) underlain by sand (mean thickness 6 cm) and clay starting at depths below 34 cm, on average. Soil samples (0-15 cm) collected in May 2000 contained 700 g kg<sup>-1</sup> of sand, 140 g kg<sup>-1</sup> of silt and 160 g kg<sup>-1</sup> of clay. The bulk density was 1.1 Mg m<sup>-3</sup> with 15.4 g organic C kg<sup>-1</sup>, 1.24 g N kg<sup>-1</sup> and pH 6.1. From 1991 to 2000, when this study began, the site was conventionally tilled for grain corn (*Zea mays* L.) production and received about 30 m<sup>3</sup> ha<sup>-1</sup> yr<sup>-1</sup> of liquid dairy manure as well as 100 to 140 kg N ha<sup>-1</sup> yr<sup>-1</sup> as urea fertilizer.

## Experimental Design

A factorial split-plot experiment was established at the site in May 2000 (Whalen et al. 2003). The factorial (tillage × crop rotation) treatments were combinations of two tillage treatments (NT or CT) and three crop rotations [corn/soybean (C/S), soybean/corn (S/C) or continuous corn (CC); corn was harvested as silage corn], for a total of six factorial treatments. The cornsoybean rotations provided crop growth and yield data for both phases of the crop rotation. The factorial plots were 20 m by 24 m, and were arranged in a randomized complete block design with four blocks. The entire site was cultivated with a disk harrow (10 cm depth) just before the experiment began. No additional tillage was done on the NT plots, but CT plots were tilled with a tandem disk (10-cm depth) each spring before seeding and with a moldboard plow (20-cm depth) each fall after harvest. Further details of the agronomic practices (cultivars, seeding dates, plant populations) were reported by Whalen et al. (2007).

Each factorial plot was split into four strips (20 m by 6 m) and four fertilizer treatments [0, 5, 10 and 15 Mg  $ha^{-1}$  (dry weight basis) of composted cattle manure] were applied randomly to the split plots. As described by Jiao et al. (2007), the 15 Mg ha $^{-1}$  compost application provided 45 kg plant-available P ha $^{-1}$ , equivalent to silage corn P requirements. Plots received supplemental inorganic fertilizers, and the target nutrient inputs were 200 kg N ha<sup>-1</sup>, 45 kg P ha<sup>-1</sup> and 125 kg K ha<sup>-1</sup> to silage corn plots, and 45 kg P ha<sup>-1</sup> and 125 kg K ha<sup>-1</sup> to soybeans. The compost came from Les Composts du Québec (Saint Henri, Quebec) and contained, on average, 401 g total C kg<sup>-1</sup>, 20.7 g total N kg<sup>-1</sup>, 5.3 g total P kg<sup>-1</sup>, 15.5 g total K kg<sup>-1</sup> and 0.60 kg H<sub>2</sub>O kg<sup>-1</sup>. All nutrient concentrations are expressed per kg compost (dry weight) basis. Compost was broadcast before seeding and either incorporated to 10 cm (CT plots) or left on the soil surface (NT plots). Corn plots received a band application of 50 kg N  $ha^{-1}$  (ammonium nitrate or calcium ammonium nitrate) and as much as 45 kg P  $ha^{-1}$  (triple superphosphate) at seeding (Jiao et al. 2006). Additional inorganic fertilizer (up to 150 kg N  $ha^{-1}$  and 125 kg K  $ha^{-1}$  from potash) was side-dressed at the four- to five-leaf stage, based on the assumption

that compost contained 25% plant-available N and K (Whalen et al. 2007). Soybeans did not receive any inorganic N fertilizer, but as much as 45 kg P ha<sup>-1</sup> was banded at seeding and up to 125 kg K ha<sup>-1</sup> was applied about 1 mo after seeding.

## **Crop and Soil Analysis**

Silage corn yields were determined each year by harvesting the grain and stover of 20 plants randomly selected from the center of each split plot. Soybean grain yield was determined by combining a swath 3-m wide by 20-m long in the center of each split plot. Silage corn and soybean yields were reported by Whalen et al. (2007). The C input from plant residues (containing an estimated 45% C) left in the field after harvest was calculated using a harvest index of 1.00 and a root:shoot ratio of 0.18 for silage corn; for soybeans, the harvest index was 0.42 and the root:shoot ratio was 0.15 (Prince et al. 2001). The N exported from plots was determined by multiplying the yield by the N content of harvested silage corn or soybean grain. Dried plant tissue was finely ground to pass through a 1-mm mesh sieve, then digested with H<sub>2</sub>SO<sub>4</sub>/H<sub>2</sub>O<sub>2</sub> (Parkinson and Allen 1975) and analyzed for N using a Lachat Quick Chem autoanalyzer (Lachat Instruments, Milwaukee, WI).

Soil samples were collected on 2005 Apr. 19, about 3 wk after the spring thaw. After pushing aside surface litter, four soil cores (0 to 15-cm depth) were delineated and collected from each split plot with a shovel (~500 g soil per core, 6-cm diameter, equal portions of soil from the entire soil layer), mixed and passed through a 6 mm mesh sieve in the field. Each composite soil sample was placed in a polyethylene bag and stored in a walk-in refrigerator (0°C) until analysis (within 1 wk for microbial biomass and extractable nutrients, about 6 mo for organic matter fractionation). Two intact cores (7.7-cm long × 8.5 cm i.d.), inserted 2–3 cm below the soil surface, were collected from each plot and represented the soil bulk density from the middle of the 0- to 15-cm layer after drying (105°C for 24 h).

Field-moist soils were sieved through 2-mm mesh in the laboratory, then 10 g of soil was extracted with 0.5 M  $K_2SO_4$  (1:4 soil:extractant) following chloroform fumigation (Voroney et al. 1993). Unfumigated soil was also extracted with 0.5 M K<sub>2</sub>SO<sub>4</sub> (1:4 soil: extractant) and analyzed for mineral N (NH<sub>4</sub>-N and NO<sub>3</sub>-N) with a Lachat Quick-Chem flow injection autoanalyzer (Lachat Instruments, Milwaukee, WI). Fumigated and unfumigated  $K_2SO_4$  extracts were digested with an alkaline persulfate solution (Cabrera and Beare 1993) and the NO<sub>3</sub>-N in persulfate digests was measured with the autoanalyzer. Microbial biomass nitrogen (MBN) was the difference in NO<sub>3</sub>-N concentration of fumigated and unfumigated samples, divided by an efficiency factor  $(K_{EN} = 0.54)$  (Joergensen and Mueller 1996). Dissolved organic nitrogen was the difference in NO<sub>3</sub>-N concentration of the digest and the mineral N (NO<sub>3</sub>-N+NH<sub>4</sub>-N) concentration in the original unfumigated extract (Cabrera and Beare 1993). Dissolved organic carbon (DOC) in fumigated and unfumigated soil extracts was determined with a Shimadzu TOC-V carbon analyzer (Shimadzu Corporation, Kyoto, Japan). Microbial biomass carbon (MBC) was the difference in DOC concentration of fumigated and unfumigated extracts, divided by an efficiency factor ( $K_{EC} = 0.45$ ) (Joergensen 1996). A subsample of field-moist soil was dried (105°C for 24 h) to determine the gravimetric moisture content.

The fractionation of soil organic matter into light and heavy fractions was based on the procedure described by Swanston and Myrold (1997). Briefly, 40 g of coarsely sieved (through 6-mm mesh) field-moist soil was mixed with 100 mL of sodium polytungstate solution (density =  $1.6 \text{ g cm}^{-3}$ , Sometu-US, Van Nuys, CA) for 1 min with a soil mixer to disrupt aggregates. After settling overnight, suspended light fraction (LF) material and the upper 1 cm of the solution were aspirated, transferred to Whatman No. 1 filter paper, and rinsed thoroughly with distilled deionized water. Soil was resuspended with another 100 mL of sodium polytungstate solution and mixed thoroughly. After settling overnight, the LF and sodium polytungstate solution were aspirated, rinsed thoroughly and added to previously collected LF. The heavy fraction (HF) was rinsed three times to remove sodium polytungstate, each time by adding distilled deionized water and aspirating the solution after the mixture settled overnight. The LF, HF and unfractionated soil samples were oven-dried (60°C for 48 h), finely ground to pass a 300mesh sieve and analyzed for organic C and total N using a Carlo Erba NC Soils Analyzer (Milan, Italy).

#### Calculations

To avoid bias due to treatment-induced differences in soil bulk density ( $\rho_b$ , in Mg m<sup>-3</sup>), the elemental mass (M<sub>element</sub>, in Mg ha<sup>-1</sup>) of C and N in soil extracts, light fraction and whole soil was calculated for an equivalent mass of soil, based on the concept of Ellert and Bettany (1995).

$$\mathbf{M}_{\text{element}} = \text{conc} \times \rho_{\text{b}} \times (T + T_{add}) \times F$$
$$\times 10\,000 \text{ m}^2 \text{ ha}^{-1} \times 0.001 \text{ Mg kg}^{-1} \qquad (1)$$

where conc = element concentration (kg C Mg<sup>-1</sup> or kg N Mg<sup>-1</sup>), T = thickness of sampled soil layer (0.15 m),  $T_{add}$  = additional thickness of soil (in m) required to achieve an equivalent soil mass, and F = the percentage of total soil mass (only considered for LF and HF fractions). The factor  $T_{add}$  was calculated as:

$$T_{add} = [(\mathbf{M}_{\text{soil, equiv.}} - \mathbf{M}_{\text{soil, sample}}) \\ \times 0.0001 \text{ ha } \text{m}^{-2}] \div \rho_{\text{b}_{\text{soil, sample}}}$$
(2)

where  $M_{soil, equiv.}$  was the equivalent mass of soil (1500 Mg soil ha<sup>-1</sup>) with a bulk density of 1.0 Mg m<sup>-3</sup> to a depth of 0.15 m,  $M_{soil, sample}$  was the soil mass

in the 0.15-m depth, according to the bulk density of the soil sample ( $\rho_{b\_soil, sample}$ , in Mg m<sup>-3</sup>). The major assumption was that C and N concentrations in representative soil samples from experimental plots (120 m<sup>2</sup>) could be directly extrapolated to a Mg ha<sup>-1</sup> basis.

# **Statistical Analysis**

Data were tested for normality using a Kolmogorov-Smirnov test and then evaluated by analysis of variance (ANOVA) in a general linear model (SAS System 9.1, SAS Institute Inc., Cary, NC). The significance of the main effects (tillage, crop rotation and the tillage  $\times$  crop rotation interaction) and the split plot effect (compost application rate) on C inputs, SOC and total N pools were evaluated. For significant (P < 0.05) effects, means were compared with a Student-Newman-Keuls test. Data presented in tables and graphs are means ( $\pm$ standard errors).

# **RESULTS AND DISCUSSION**

# Carbon Inputs from Crop Residues and Compost Applications

During the 5 yr (2000–2004) of this study, crop residues provided a cumulative C input of about 5.2 to 7.9 Mg C ha<sup>-1</sup> (Table 1). More silage corn and soybean grain were harvested from CT than NT plots during 3 of the 5 study years (Whalen et al. 2007), which contributed to the greater cumulative C input in CT than NT systems (Table 1). Crop rotations with soybean provided a greater C input than continuous corn because more crop residues (roots, stems and leaves) remained in plots after soybean grain was harvested than when silage corn was harvested (Table 1). Compost applications provided a significant (P < 0.05) input of C and plots receiving 15 Mg ha<sup>-1</sup> yr<sup>-1</sup> of compost had five to seven times more C input than plots that did not receive compost (Table 1).

# Soil Organic Carbon Pools

Despite the considerable C input to experimental plots due to agricultural practices implemented during the period 2000-2004, only compost application had a significant (P < 0.05) effect on the total SOC and MBC pools of soils collected in April 2005 (Table 2). Soil C pools were not affected by tillage, which is consistent with other studies from Eastern Canada (VandenBygaart et al. 2003), nor was there a difference between continuous corn and corn-soybean rotations. The MBC concentration was greater in plots receiving 15 Mg ha<sup>-1</sup> yr<sup>-1</sup> of compost than plots receiving no compost (Fig. 1). This was probably related to the presence of readily decomposable C in the compost. Generally, row-cropped agroecosystems have a greater MBC concentration when animal manure or compost are applied, compared with unfertilized or inorganically fertilized agroecosystems (Garcia-Gil et al. 2000; Marschner et al. 2003; Deng et al. 2006).

Size-density fractionation may isolate C from an active C pool within the total SOC pool and hence serve as an indicator of short-term changes in SOC, including SOC accumulation in agroecosystems (Christensen 1992; Janzen et al. 1992; Ellert and Gregorich 1995). Compost applications did not affect the mass and C content of the LF (Fig. 2). We note that the LF obtained by density separation in this study had an average C/N ratio of 18.3 (Table 2), which is similar to the C/N ratio of 19.1 ( $\pm 0.6$ ) in LF from agricultural soils reported by Gregorich et al. (2006). However, there was more variability associated with the LF-C and LF-N pools than any other soil C or N pool evaluated in this study (Table 2), which explains

Table 1. Estimated carbon input (Mg C  $ha^{-1}$ ) from corn silage and soybean residues, plus composted cattle manure applied to a sandy-loam soil from 2000 to 2004. Crops were directly seeded without tillage (NT) or planted in a conventional tillage system (CT). Values are the mean (standard errors in parentheses)

		Compost application rate (Mg ha <sup><math>-1</math></sup> yr <sup><math>-1</math></sup> , dry weight)					
Tillage	Crop rotation <sup>z</sup>	0	5	10	15		
NT	C-C-C-C-C	5.32 (0.22) <sup>y</sup>	15.4 (0.17)	26.2 (0.29)	36.6 (0.36)		
	C-S-C-S-C	5.21 (0.50)	15.4 (0.51)	25.8 (0.61)	36.8 (0.59)		
	S-C-S-C-S	7.31 (0.32)	18.1 (0.08)	28.7 (0.25)	39.1 (0.21)		
CT	C-C-C-C-C	6.32 (0.15)	16.4 (0.31)	26.8 (0.27)	37.6 (0.28)		
	C-S-C-S-C	6.89 (0.35)	17.4 (0.47)	27.6 (0.23)	38.3 (0.31)		
	S-C-S-C-S	7.88 (0.28)	18.1 (0.17)	28.7 (0.28)	39.1 (0.39)		
Source of variation	d.f. <sup>x</sup>						
Block	3	NS	NS	NS	NS		
Tillage	1	*	***	*	+		
Crop Rotation	2	***	**	***	**		
Tillage x Rotation	2	NS	NS	NS	NS		

<sup>z</sup>C-C-C-C = continuous corn; C-S-C-S-C and S-C-S-C-S = corn-soybean rotations.

<sup>y</sup>The estimated C input was from plant residues (corn roots; soybean stems, leaves and roots) not removed from the field at harvest. An additional 2045, 4090 or 6135 kg C ha<sup>-1</sup> yr<sup>-1</sup> came from the annual application of 5, 10 or 15 Mg ha<sup>-1</sup> (dry weight) of compost.

 $^{x}$ d.f. = degrees of freedom in analysis of variance.

 $\dagger$ , \*, \*\*, \*\* Significant at P < 0.1, P < 0.05, P < 0.01 and P < 0.001, respectively; NS, not significant.

	d.f. <sup>y</sup>	Soil organic C pool $(Mg C ha^{-1})^{z}$			Soil N pool (Mg N ha <sup>-1</sup> ) <sup>z</sup>				
Source of variation		SOC	LF-C	MBC	DOC	TN	LF-N	MBN	NO <sub>3</sub> -N
Block	3	*	NS	***	***	***	NS	NS	NS
Tillage	1	NS	NS	NS	NS	NS	NS	NS	NS
Crop rotation	2	NS	NS	NS	NS	NS	NS	NS	NS
Till. × Rotation	2	NS	NS	NS	NS	NS	NS	NS	**
Compost	3	***	NS	***	NS	***	NS	NS	**
ANOVA $R^2$		0.58***	0.26NS	0.57***	0.73***	0.68***	0.26NS	0.28NS	0.42*
Mean		30.5	4.63	0.179	0.104	2.83	0.254	0.083	0.016
Coefficient of variation (%)		11	65	35	16	10	65	46	20

Table 2. Treatment effects on selected soil organic C and N pools, expressed on an equivalent mass basis (Mg C ha<sup>-1</sup> or Mg N ha<sup>-1</sup>) in a sandy loam soil

 $^{z}SOC = soil organic C; LF-C = light fraction C; MBC = microbial biomass C; DOC = dissolved organic C; TN = total N; LF-N = light fraction N; MBN = microbial biomass N.$ 

<sup>y</sup>d.f. = degrees of freedom in analysis of variance.

\*, \*\*, \*\*\*Significant at P < 0.05, P < 0.01 and P < 0.001, respectively; NS, or not significant.

why there was no difference in the LF pools that could be attributed to agricultural treatments (tillage, crop rotations, compost applications).

The sandy-loam soil had a lower soil bulk density, contained more SOC and had larger total SOC, total N and NO<sub>3</sub>-N pools when amended with 15 Mg ha<sup>-1</sup> yr<sup>-1</sup> of compost, compared with the plots with no compost (Table 3). The active SOC pool (MBC plus LF) accounted for 14 to 17% of the total SOC pool (Table 3). The LF alone was 13 to 16% of the total SOC pool, which is slightly more than the average proportion (7.5% + 0.7) of LF in the SOC of agricultural soils, but within the range (0.8 to 35.8% of SOC) reported by Gregorich et al. (2006). Although compost applications significantly (P < 0.05) increased the SOC and total N storage, there was also an increase in SOC and total N storage in plots that did not receive compost (Table 3). This may indicate that the SOC and total N pools were depleted under previous agricultural management at the site, but we cannot provide a reliable explanation because we lack the complete historical

 $\mathbf{y}_{\text{composition}}^{200} \underbrace{\mathbf{y}_{100}}_{0} \underbrace{\mathbf{y}_{100}}_{0} \underbrace{\mathbf{y}_{100}}_{0} \underbrace{\mathbf{y}_{100}}_{0} \underbrace{\mathbf{y}_{100}}_{0} \underbrace{\mathbf{y}_{100}}_{0} \underbrace{\mathbf{y}_{100}}_{0} \underbrace{\mathbf{y}_{100}}_{1} \underbrace{\mathbf{y}_{100}}_{1}$ 

record of agricultural practices prior to the establishment of this experiment.

Christopher and Lal (2007) reported that fertilized cropland in humid regions of Canada would sequester 0.07 to 0.68 Mg C ha<sup>-1</sup> yr<sup>-1</sup>, which is less than the gain of 0.93 Mg C ha<sup>-1</sup> yr<sup>-1</sup> in plots that received inorganic NPK fertilizer only (0 Mg  $ha^{-1}$  yr<sup>-1</sup> of compost, Table 3). The gain in SOC we report is within the range of 0.02 to 1.69 Mg C ha<sup>-1</sup> yr<sup>-1</sup> gained from C sequestration in fertilized cropland located in humid regions of the United States. The sequestration rate estimated by Christopher and Lal (2007) for humid cropland in Canada receiving manure and fertilizer (0.05 to  $0.15 \text{ Mg C} \text{ ha}^{-1} \text{ yr}^{-1}$ ) has not yet been validated. However, their values are more than 10 times lower than the SOC gain of 1.35 to 2.02 Mg C ha<sup>-1</sup> yr<sup>-1</sup> in the compost-amended plots (Table 3). Our results can not be compared directly with C sequestration estimates (i.e., an increase in the SOC pool from crop residues) because C inputs came from crop residues and compost



**Fig. 1.** Microbial biomass C concentration in a sandy-loam soil receiving compost (0 to 15 Mg ha<sup>-1</sup> yr<sup>-1</sup> of compost, dry weight) from 2000 to 2004. Values are the mean and standard errors (n = 24); bars with the same letter are not statistically different (P < 0.05, Student-Newman-Keuls test).

**Fig. 2.** Light fraction (LF) weight and C content of the LF in a sandy-loam soil receiving compost (0 to 15 Mg ha<sup>-1</sup> yr<sup>-1</sup> of compost, dry weight) from 2000 to 2004. Values are the mean and standard errors (n = 24).

Table 3. Bulk density, soil organic C (SOC) and total N pools, expressed on an equivalent mass basis (Mg C ha <sup>-1</sup>	or Mg N ha <sup>-1</sup>	) in a sandy-loam soil.
Plots received five annual applications of compost (0 to $15 \text{ Mg ha}^{-1} \text{ yr}^{-1}$ , dry weight) from 2000 to 2004	-	

Compost rate (Mg ha <sup>-1</sup> yr <sup>-1</sup> )	Bulk density (Mg m <sup>-3</sup> )	Total SOC pool (Mg C ha <sup>-1</sup> )	Active SOC pool <sup>z</sup> (Mg C ha <sup>-1</sup> )	Change in SOC storage <sup>y</sup> (Mg C ha <sup>-1</sup> yr <sup>-1</sup> )	Total N pool (Mg N ha <sup>-1</sup> )	NO <sub>3</sub> -N pool (Mg N ha <sup>-1</sup> )	Change in total N storage <sup>x</sup> (Mg N ha <sup>-1</sup> yr <sup>-1</sup> )
0	1.02 <i>a</i>	27.7 <i>c</i>	3.72 <i>a</i>	+0.93c	2.62 <i>c</i>	0.015b	+0.15c
5	0.98b	29.9b	4.93 <i>a</i>	+1.35b	2.77bc	0.015b	+0.18bc
10	0.97 <i>b</i>	31.1 <i>ab</i>	5.09 <i>a</i>	+1.61ab	2.89 <i>ab</i>	0.016b	+0.21ab
15	0.93 <i>c</i>	33.2 <i>a</i>	5.47 <i>a</i>	+2.02a	3.05 <i>a</i>	0.018 <i>a</i>	+0.24a

<sup>z</sup>Active SOC pool = light fraction C+microbial biomass C.

<sup>y</sup>Change in SOC storage = [Total SOC pool in 2005 – Total SOC pool in 2000 (23.1 Mg C ha<sup>-1</sup>)]  $\div$ 5 yr. <sup>x</sup>Change in total N storage = [Total N pool in 2005 – Total N pool in 2000 (1.86 Mg N ha<sup>-1</sup>)]  $\div$ 5 yr.

Within a column, values with the same letter are not statistically different (P < 0.05, Student-Newman-Keuls test).

in our study. However, plots receiving no compost gained 0.93 Mg C ha<sup>-1</sup> yr<sup>-1</sup> during our study, suggesting that the values provided by Christopher and Lal (2007) are underestimated.

Other authors have reported an increase in SOC following several years of regular compost or manure applications (Fortuna et al. 2003; Hao et al. 2003). We found that the increase in SOC was related to soil aggregation, as more water-stable aggregates (>2 mm)were formed in compost-amended plots during the study (Whalen et al. 2003; Jiao et al. 2006). This suggests that the SOC accumulation in this soil was linked to C storage in macro-aggregates. The physical protection of SOC in macro-aggregates is not expected to provide long-term SOC storage, since SOC is better protected from decomposition within micro-aggregates (<0.25 mm)than macro-aggregates (Six et al. 2002). Yet, long-term fertility experiments in Thyrow, Germany, demonstrated that farmyard manure applications (alone, or in combination with inorganic NPK fertilizers and lime) increased the SOC content of a sandy soil by 25% or more, and the SOC level remained stable when 30 Mg  $ha^{-1}$  of farmvard manure was applied every second year (Ellmer et al. 2000). Judicious use of farmyard manure may compensate for C losses from soils and maintain the SOC pools in cropland (Rasmussen et al. 1998) and grassland systems (Lee et al. 2007).

#### **Soil Nitrogen Pools**

The total N and NO<sub>3</sub>-N pools were greater in plots that received 15 Mg ha<sup>-1</sup> yr<sup>-1</sup> of compost than no compost (Tables 2 and 3). There was less NO<sub>3</sub>-N in NT plots that were under soybean production in 2004 than in most other treatments (Fig. 3). Spring thaw is often accompanied by a large flux of N<sub>2</sub>O, and some studies indicate that soils under NT and soybean production in this region may emit more N<sub>2</sub>O than those under CT, or in corn production (Gregorich et al. 2005). This could explain the results in Fig. 3, if all plots had similar NO<sub>3</sub>-N concentrations prior to spring thaw. Compost applications increased the size of the total N pool, but the NO<sub>3</sub>-N pool was similar in plots that received inorganic fertilizers and up to 10 Mg  $ha^{-1}$  yr<sup>-1</sup> of compost. Fertilizer inputs have little effect on soil NO<sub>3</sub>-N concentrations in corn production systems when agronomic rates (up to 200 kg N ha<sup>-1</sup>) are applied (Dolan et al. 2006; Grignani et al. 2007; Wander et al. 2007). Since compost applications had a marginal effect on the NO<sub>3</sub>-N pool, and did not affect the light fraction N or MBN pools, it seems likely that gain in total N was from an increase in stable organic N compounds, but this should be confirmed.

The N exported from experimental plots in silage corn varied from year to year, due to the yield fluctuations in response to climatic conditions (Whalen et al. 2007). In 2002 and 2004, more N was exported in silage corn grown in plots receiving inorganic NPK fertilizer only (no compost) than the 45 Mg ha<sup>-1</sup> compost application (Fig. 4). The cumulative N export in silage corn was equivalent to between 43 and 96% of the N input from fertilizer N and compost N during the period 2000–2004, calculated from data in Table 4. This does not represent the actual N balance, since we did not account for N



Fig. 3. Soil NO<sub>3</sub>-N concentration in a sandy-loam soil, as affected by 5 yr of tillage and crop rotations (2000-2004). The crop harvested in fall 2004 is written in full (Corn, Soy), as is the crop rotation (CC = continuous corn, CS and SC = cornsoybean rotations) and tillage system (CT = conventional tillage, NT = no-till). Values are the mean and standard errors (n = 16). Bars with the same letter are not statistically different (P < 0.05, Student-Newman-Keuls test).



**Fig. 4.** Nitrogen export in corn silage related to compost applications (0 to 15 Mg ha<sup>-1</sup> yr<sup>-1</sup> of compost, dry weight) from 2000 to 2004. Values are the mean and standard errors (n = 16). Bars with the same letter are not statistically different (P < 0.05, Student-Newman-Keuls test).

mineralization from soybean residues in the cornsoybean rotations or the N supplied from soil organic matter. Soybean plots receiving compost, which provided 106 to 318 kg N ha<sup>-1</sup> yr<sup>-1</sup>, did not have more N export in soybean grain (Fig. 5). We do not know the fate of compost N applied to soybean plots, but N in excess of crop requirements could have been lost from plots through gaseous emissions or leaching. Sey et al. (2008) reported more N<sub>2</sub>O emissions from compost-amended than inorganically fertilized plots at this experimental site, with the majority of N<sub>2</sub>O emissions occurring in the spring. Information on the N leaching through the soil profile (to 60-cm depth) of these plots will be the subject of a future communication.

#### CONCLUSIONS

This study demonstrated that annual applications of composted cattle manure provided a significant C input and increased SOC pools in agroecosystems under silage corn and soybean production. Compost-amended plots exhibited a gain of 1.35 to 2.02 Mg C ha<sup>-1</sup> yr<sup>-1</sup> from crop residues and compost C inputs. Also, there was a gain of 0.93 Mg C ha<sup>-1</sup> yr<sup>-1</sup> in plots that received inorganic NPK fertilizers (no compost), which exceeds published estimates for humid croplands in Canada. Modest gains in the total N pool, from 0.18 to 0.24 Mg N ha<sup>-1</sup> yr<sup>-1</sup>, were attributed to compost applications

Table 4. Annual N input to a sandy-loam soil and cumulative N export by silage corn harvested from experimental plots from 2000–2004

Compost rate (Mg ha <sup>-1</sup> yr <sup>-1</sup> )	Fertilizer N <sup>z</sup> (kg N ha <sup>-1</sup> yr <sup>-1</sup> )	$\begin{array}{c} \text{Compost } N^{y} \\ (\text{kg N ha}^{-1} \text{ yr}^{-1}) \end{array}$	Cumulative N export (kg N ha <sup>-1</sup> )
0	200	0	960
5	150	106	882
10	100	212	771
15	50	318	799

<sup>z</sup>Ammonium nitrate (34-0-0) or calcium ammonium nitrate (27.5-0-0). <sup>y</sup>Total N input, based on 20.7 g N kg<sup>-1</sup> compost (dry weight).



**Fig. 5.** Nitrogen export in soybean grain as affected by compost applications (0 to 15 Mg ha<sup>-1</sup> yr<sup>-1</sup> of compost, dry weight) from 2000 to 2004. Values are the mean and standard errors (n=8). Bars with the same letter are not statistically different (P < 0.05, Student-Newman-Keuls test).

The increase in SOC and total N pools was achieved with agronomic rates of compost and inorganic fertilizer, selected to supply the N, P and K required for silage corn production. Compost applications could be a good option to build SOC and total N pools on farms in Eastern Canada.

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