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Manuring and rotation effects on soil organic carbon concentration for different aggregate size fractions on two soils in northeastern Ohio, USA

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Abstract

Soil carbon (C) sequestration is important to the mitigation of increasing atmospheric concentration of CO_2. This study was conducted to assess soil aggregation and C concentration under different management practices. The effects of crop rotation, manure application and tillage were investigated for 0–5 and 5–10 cm depths on two silt loam soils (fine-loamy, mixed, active, mesic Aquic Fragiudalfs and fine-loamy, mixed, active, mesic Aeric Fragiadalf) in Geauga and Stark Counties, respectively, in northeastern Ohio, USA. Wet sieve analysis and gravity fractionation techniques were used to separate samples in aggregate and particle size groups, respectively. In the Stark County farms water stable aggregate (WSA) is higher in wooded (W) controls (WSA = 94.8%) than in cultivated soils with poultry manure (PM, 78.7%) and with chemical fertilizers (CF, 79.0%). Manure applications did not increase aggregation compared to unmanured soils. The C concentrations (%) within aggregates (C_{agg}) are higher in W than in cultivated soils (W = 5.82, PM = 2.11, CF = 1.96). Soil C (%) is enriched in the clay (W = 9.87, PM = 4.17, CF = 4.21) compared to silt (4.26, 1.04 and 0.98, respectively) and sand (0.93, 0.14 and 0.32, respectively) fractions. In the Geauga County farm, continuous corn (CC) with conventional tillage has lower WSA (83.1%) than soils with rotations (R) (93.9%), dairy manure (DM) application (93.2%) and no-till (NT) (91.1%). The C concentrations within macroaggregates (C_{agg}) were higher in W soils (4.84%) than in cultivated soils (ranging from 2.65 to 1.75%). The C (%) is enriched in clay (W = 8.56, CC = 4.18, R = 5.17, DM = 5.73, NT = 4.67) compared to silt (W = 2.35, CC = 0.90, R = 0.96, DM = 1.57, NT = 1.06) and sand (W = 0.44, CC = 0.33, R = 0.13, DM = 0.41, NT = 0.18). Cultivation decreased C concentration whereas reduced tillage, rotation and manure enhanced C concentration in soil.

Keywords: Carbon sequestration; Soil organic carbon; Aggregation; Soil management; Cropping systems; Soil structure; Conservation tillage

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1. Introduction

Aggregation and soil organic carbon (SOC) concentration represent integrative effects of soil type, environment, plant species, and soil management

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practices including crop rotations, tillage and fertilizer management (Martens and Frankenberger, 1992; Nyamangara et al., 1999; Martens, 2000b). The SOC is a primary factor influencing soil structure (Kay, 1998), and in turn is influenced by the dynamics of soil structure. Agronomic productivity is affected by environmental factors and nutrient availability, which in turn is influenced by management practices such as manure application and fertilization.

Crop species influence soil structure and SOC concentration; the extent of this influence is determined by numerous factors including crop species, productivity, canopy structure, root physiology and root function and pattern (Chan and Heenan, 1996). Through complex interactions and feedback mechanisms, different crops influence soil chemical and biological properties and SOC concentration, which impact soil structure (Chan and Heenan, 1996). Residue management can have a substantial influence on aggregation and SOC concentration (Follett, 2001; Franzluebbers, 2002). Retention of crop residues enhances SOC concentrations, macroaggregation and soil physical properties (Hulugalle and Cooper, 1994; Unger, 1997; Kushwaha et al., 2001). The amount, chemical composition and decomposition rate of crop residues have varying influences on aggregation and SOC depending on the crop species (Martens, 2000b). Macroaggregates have wider C:N ratio than microaggregates (Kushwaha et al., 2001). Corn (*Zea mays*) residue has high phenol concentration which is linked to increased water stable aggregate (WSA) formation as well as high C:N ratio, and high SOC and carbohydrate concentrations (Martens, 2000a). Soybeans (*Glycine max*) can have deleterious effects on soil structure through limited return of biomass to the soil and residue biochemistry, including low concentration of phenols (Martens, 2000a, 2000b).

There is not a direct relationship between legumes and SOC concentration and aggregation, due to the differences in legume plants and the many factors involved in aggregation and SOC. The low quality and quantity of residues from soybeans does not promote improved aggregation and SOC concentration (Martens, 2000a, 2000b). The high root density of some legumes and increased microbial activity can promote aggregation (Haynes and Beare, 1997).

Different root systems affect aggregation differently. Root systems influence soil structure through their physiology and functions. Extensive root systems, root exudates and microbial activity, particularly fungi, improve soil aggregation (Haynes and Beare, 1997; Traore et al., 2000). Aggregate stability in soils with non-legumes is correlated with root mass (Haynes and Beare, 1997). The roots of legumes have low C:N ratio and low root density compared to corn and other cereals resulting in lower aggregation, although in some cases the increased microbial activity may account for increased aggregation (Haynes and Beare, 1997).

Crop rotations improve soil structure compared to continuous monocropping, particularly with the inclusion of pasture species. Soil aggregate stability is generally higher under continuous alfalfa (*Medicago sativa*). Incorporating legumes in the rotation cycle improves aggregate stability especially that of microaggregates compared to continuous corn (Raimbault and Vyn, 1991), although corn–soybean rotations do not always increase SOC concentration compared to continuous corn (West and Post, 2002; Hao et al., 2002). Long-term field studies suggest that enhanced crop rotation complexity produces long-term increases in SOC concentration (West and Post, 2002). After 30 years of crop rotations, annual SOC gains ranged from 0.06 to 0.22 Mg ha^{-1} $year^{-1}$ for fields in Canada (Campbell et al., 2000).

Nutrient management through chemical fertilization and manure applications generally increases aggregation, SOC concentration and microbial communities (Haynes and Naidu, 1998; Schjonning et al., 2002; Munkholm et al., 2002; Hao et al., 2002). The primary effect of improved nutrient management is on increasing plant productivity, SOC concentration and biological activity (Haynes and Naidu, 1998; Graham et al., 2002). Manure applications increase SOC concentration, aggregate stability and soil biological activities all of which have been associated with improved soil structure (Martens and Frankenberger, 1992; Haynes and Naidu, 1998; Nyamangara et al., 1999; Aoyama et al., 2000). Dairy manure can alter soil aggregate stability against slaking and dissolution and dispersive actions (Nyamangara et al., 1999; Pare et al., 1999). Long-term manure applications increase SOC through the addition of organic matter (OM) in the manure and through increased OM return in crop residues due to increased crop production (Whalen and Chang, 2002). The SOC concentration in sand is affected by management practices, while that in clay is more influenced by chemical and physical environment (Khanna et al., 2001). In coarse-textured soils, however, manuring can improve aggregation (Nyamangara et al., 1999). In fine-textured soils manuring may decrease aggregate stability (Pare et al., 1999). Increased microbial activity and SOC concentration in poultry manure treated soils may contribute to increased aggregate stability (Martens and Frankenberger, 1992). Long-term field studies in the North America, and China indicate that manuring increases SOC (Liu et al., 2003; Whalen and Chang, 2002). In a 25 year study, SOC progressively increased with manure applications at an average rate of 0.181 g kg^{-1} Mg^{-1} of manure (Hao et al., 2003).

Reduced and no-till systems have higher SOC concentrations compared with conventional tillage practices (Salinas Garcia et al., 1997). Conservation tillage reduces biomass mineralization, decreases oxygen availability and increases SOC concentration (Martens, 2000b). Long-term experiments in the USA, Europe and China indicate that reduced tillage increases SOC concentration although the increases may not be apparent for years (West and Post, 2002; Eivazi et al., 2003; Liu et al., 2003). Tillage studies in southern Illinois show that after 8 years of no-till (NT), chisel plow (CP), and moldboard plow (MP) treatments SOC and POM decreased in tilled compared to no-till soils. SOC decreased in CP and MP from 17 to 30% compared to no till and POM decreased from 22 to 43% (Hussain et al., 1999).

Soil erosion resulting from soil mismanagement results in the loss of SOC (Lal, 2003b). The erosion process includes the break up of aggregates, transport and deposition of particles. These processes alter the availability SOC for mineralization. Management practices that reduce soil erodibility, maintain soil structure or increase biomass returned to soil are beneficial for C sequestration. Management practices such as reduced tillage and increased C inputs through residue management and manuring improve soil structure, reduce erosion and C loss through mineralization and CO_2 emissions (Hao et al., 2002; Lal, 2003a, 2003b).

The objective of this study was to assess SOC concentration under different management practices under on-farm conditions in northeastern Ohio and to establish a cause–effect relationship between SOC concentration on the one hand and aggregation and particle size distribution on the other.

2. Materials and methods

2.1. Sites and soil descriptions

Soil analysis was done in fields with different management practices on farms, in Geauga and Stark Counties in northeastern Ohio, USA (41°29′N, 081°07′W and 40°57′N, 081°15′W, respectively). The predominant soil type in Geauga County is classified as Canfield silt loam (fine-loamy, mixed, active, mesic Aquic Fragiudalfs) (USDA, 1982). Sampling sites on this farm were chosen with regards to differences in management practices: manuring, tillage methods and crop rotation (Table 1). In all, there were four management treatments and a control: (1) alfalfa-alfalfa–corn-corn–wheat (*Triticum asetivum* L.) rotation (ACW) with lime (7 Mg ha^{-1}) and dairy manure (DM) added during corn and wheat cycle at 4.6 Mg ha^{-1} dry weight; (2) meadow-meadow–corn-corn–wheat rotation (MCW) with chemical fertilizers (CF). Fertilizer (NPK 19–11–4, 500 kg ha^{-1}) and lime (7 Mg ha^{-1}) were applied during the corn cycle and the meadow rotation was seeded with a mixture of orchard grass (*Dactylis glomerata* L.) and alfalfa; (3) monocropping corn with CF (NPK 19–11–4, 500 kg ha^{-1}) and no manure; (4) corn–hay (CH) rotation under no-till for 12 years with CF (NPK 19–11–4, 500 kg ha^{-1}) and no manure; (5) a wooded control of 40 years of tree regrowth. Chemical pest control was applied at seeding and 6 weeks following seeding in the no-till and no rotation fields under corn. Minimum tillage used includes chisel plowing and disking once in spring.

The soil in the two Stark County farms is classified as Ravenna-Canfield silt loam (fine-loamy, mixed, active, mesic Aeric Fragiadalf) (USDA, 1971). Sampling sites were on two adjacent farms with similar soil types but different management history (Table 1). There were two management treatments and a wooded control: (1) corn–soybean rotations (RPM) with minimum till, including chisel plowing and disking, for about 13 years with poultry manure (PM), (2) CF (RCF), and (3) woodlot control that has not been cultivated for 60 years as a control. Poultry

Table 1
Field management history of Geauga and Stark County farms

Crop/rotation treatment	Years	Fertilizer	Tillage	Other	Comments
Geauga County farm					
Wooded control	40+	None	None	None	Hardwood trees
No rotation (continuous corn)	3	Chemical fertilizer NPK (19–11–4) 500 kg ha^{-1}	Minimum till chisel plow and disc over once	Herbicide application at planting and 6 weeks after planting	Previously under wheat and soybean
Rotation with manure (alfalfa–corn–wheat)	20	Dairy manure 4.6 Mg ha^{-1} (2000)	Minimum till chisel plow and disc over once	Lime 7 Mg ha^{-1} (2000)	Sampling year was second year of alfalfa cycle. Manure applied 2 years prior to sampling
Rotation without manure (meadow–corn–wheat)	20	Chemical fertilizer NPK (19–11–4) 500 kg ha^{-1}	Minimum till chisel plow and disc over once	Lime 7 Mg ha^{-1} (2000)	Sampling year was second year of meadow
No-till rotation (corn–hay)	12	Chemical fertilizer NPK (19–11–4) 500 kg ha^{-1}	No-till	Herbicide application at planting and 6 weeks after planting	Second year corn cycle
Stark County farms					
Wooded control	60	None	None		Wood
Rotation without manure		Chemical fertilizers, NPK	Minimum chisel plow and disc over once	Sampled during soybean cycle	Rotation without manure
Rotation with poultry manure (PM)	13	Poultry manure every 2–3 years, 7–10 dry weight Mg ha^{-1}	Minimum chisel plow and disc over once	Sampled during corn cycle. Last PM application 2 years prior to sampling	Rotation with poultry manure (PM)

manure was applied at a rate of 4.5–11.2 Mg ha^{-1} dry weight.

2.2. Soil sampling

Soil samples were collected from 0 to 5 and 5 to 10 cm depths. Composites of five sub-samples at each depth were taken along the field gradient, with five replicates for each sample. Samples were gently broken by hand, air-dried and passed through an 8 mm sieve. Aggregates retained on a 4.75 mm sieve were used for the wet sieving analysis (Yoder, 1936). Part of the sample was ground and sieved through a 2 mm sieve.

2.3. Water stable aggregate fractionation

A 20 g sample of air-dried aggregates (4.75–8 mm) was brought to constant soil water content and placed on the top sieve of five nested sieves (4.75, 2.00, 1.00, 0.50 and 0.25 mm) in a container of de-ionized water. The aggregates were allowed to wet by capillarity for 30 min and then gently wet-sieved with a vertical motion (5 cm amplitude and 25 strokes min^{-1}) for 30 min (Yoder, 1936; Kemper et al., 1985; Kemper and Rosenau, 1986). Aggregate fractions were recovered, air-dried, weighed and analyzed for SOC concentration using dry combustion method (Nelson and Sommers, 1982). Fractions were adjusted for primary particles by removing and weighing stones, then subtracting the weight of primary particles. The wet sieve data were used to compute water stable aggregates (WSA%), geometric mean diameter (GMD) and mean weight diameter (MWD) (Youker and McGuinness, 1956).

2.4. Particle size fractionation

A 50 g sample of air-dried and ground sample (<2 mm) was dispersed in de-ionized water (soil:-water ratio 1:2.5) in a reciprocal shaker (100–2.5 cm length strokes min^{-1}) overnight (16 h) (Puget et al., 1995). Ultrasound (15 min, 80 W) was used to further disperse the soil slurry smaller than 50 μm. Samples were wet-sieved to recover sand (>0.05 mm) and particulate organic matter (POM) fractions. The soil suspension was transferred to an automatic clay separator (Rutledge et al., 1967). Clay- and silt-sized organo-mineral particles were separated by siphoning at 8 cm depth after 8 h of sedimentation at 25 °C. This procedure was repeated until a clear suspension was obtained. Particle size fractions were dried at 60 °C and analyzed for SOC concentration.

2.5. Carbon analysis

Soil subsamples of aggregate fractions were ground using a ball mill. The SOC concentration was determined by the dry combustion method using a NC 2100 Soil (ThermoQuest CE Instruments, Milan, Italy). Size fractions were ground using a mortar and pestle and passed through 250 μm sieve, 1 g samples were analyzed using an Elementar Vario Max CN Analyzer.

2.6. Statistical analysis

Data from this study were analyzed using GLM and ANOVA model in SAS statistical software. Differences were determined by using least squared means (LSMEANS) with differences in the $P < 0.05$ significance level (SAS Institute and Inc., 1989).

3. Results and discussion

3.1. Water stable aggregates

Aggregation tended to decrease with depth although the differences were not always statistically significant. Aggregation was the highest in the wooded control soil; it was also high in fields with less disturbance, more complex cropping systems, high quality and quantity of crop residues and receiving manure. In Geauga County the fields continuously cultivated with corn (CC) using CF had lower aggregation than uncultivated soils and fields with rotations, manuring and no-till (Table 2). These trends may be attributed to tillage disturbances and low diversity in plant species even though the corn residues tend to enhance aggregate stability by contributing large quantities of high quality organic matter. The reduction of tillage for the two rotations and no-till enhances aggregation. The fields under rotation with and without manure were under the second-year alfalfa and alfalfa/orchard grass mixture, respectively, which have high root masses that contribute to aggregation. Carry over from previous years treatment with manure in the AWC rotation also contributes to increases in aggregate stability.

In Stark County soil under rotation with CF tended to have higher aggregation than rotation with manure. Uncultivated soil had significantly higher WSA, GMD and MWD than cultivated soils in the 0–5 and 5–10 cm depths (Table 3). There was a large quantity of corn residues in RCF from the previous year's corn cycle, but a little residue in the RPM field from the previous years soybean cycle. The corn residues enhance aggregation in the RCF (Martens, 2000b) and

Table 2
Land use and management effects on structural properties of Canfield silt loam in a Geauga County farm

Treatment	Water stable aggregate (%)	Geometric mean diameter (mm)	Mean weight diameter (mm)
0–5 cm			
Wooded control	95.4a	2.0a	5.4a
No rotation (continuous corn)	83.1b	1.5b	3.2b
Rotation with manure (alfalfa–corn–wheat)	93.2a	2.0a	5.4a
Rotation without manure (meadow–corn–wheat)	93.9a	2.2a	5.7a
No-till rotation (corn–hay)	91.1a	2.0a	5.4a
LSD (0.05)	6.0	0.1	0.6
5–10 cm			
Wooded control	92.0a	1.9a	4.7a
No rotation (continuous corn)	86.8a	1.5b	3.5b
Rotation with manure (alfalfa–corn–wheat)	93.0a	1.9a	5.0a
Rotation without manure (meadow–corn–wheat)	91.8a	2.0a	5.0a
No-till rotation (corn–hay)	87.8a	1.9a	4.9a
LSD (0.05)	6.7	0.2	0.9

Figures within a column with the same letter are statistically similar ($P = 0.05$).

Table 3
Land use and management effects on structural properties of Ravenna-Canfield silt loam in Stark County farms

Treatment	Water stable aggregate (%)	Geometric mean diameter (mm)	Mean weight diameter (mm)
0–5 cm			
Wooded control	94.8a	2.0a	5.5a
Rotation without manure	79.0b	1.4b	2.9b
Rotation with poultry manure	78.7b	1.2c	2.0c
LSD (0.05)	6.2	0.1	0.6
5–10 cm			
Wooded control	91.9a	1.9a	4.8a
Rotation without manure	80.5ab	1.4b	2.9b
Rotation with poultry manure	77.8b	1.3b	2.5b
LSD (0.05)	12.5	0.2	1.1

Figures within a column with the same letter are statistically similar ($P = 0.05$).

the PM in the RPM soil enhances aggregation (Martens and Frankenberger, 1992).

3.2. Particle size and soil organic carbon concentration

The wooded soils have lower concentration of sand and higher concentration of POM than cultivated soils (Tables 4 and 5). The cultivated soils have lower silt concentrations than uncultivated soils.

The SOC concentration is associated more with clay than sand and silt fractions (Figs. 1–4). The SOC concentration associated with clay (C_{cl}) is higher in the 0–5 cm than 5–10 cm depth; this is significant ($P = 0.05$) in the uncultivated soils and those for the Geauga County rotation without manure. The C_{cl} is highest in uncultivated, wooded control. The C_{cl} is elevated in cultivated soils with manure, rotations and no-till compared to soil under monocropping with CF (Fig. 1). At 5–10 cm depth, manured soils have higher C_{cl} than other cultivation treatments, although uncultivated soils have higher C_{cl} (Fig. 2).

In Stark County, the uncultivated field has the highest C_{cl} while there is no difference in C_{cl} among the cultivated soils (Figs. 3 and 4). The similarity in SOC concentration for different particle size fractions

Table 4
Land use and management effects on textural properties of Canfield silt loam in a Geauga County farm

Treatment	Particle size (%)			Particulate organic matter (%)
	Sand	Silt	Clay	
0–5 cm				
Wooded control	14.9d	70.2a	14.9b	8.3a
No rotation (continuous corn)	32.4bc	47.8c	19.9a	2.4b
Rotation with manure (alfalfa–corn–wheat)	26.5c	57.6b	15.9b	3.1b
Rotation without manure (meadow–corn–wheat)	40.2a	45.0c	14.9b	3.5b
No-till rotation (corn–hay)	35.3ab	48.3c	16.4ab	4.3ab
LSD (0.05)	7.1	6.6	3.7	4.3
5–10 cm				
Wooded control	18.6b	65.7a	15.6a	2.6ab
No rotation (continuous corn)	34.4a	47.0c	18.6a	1.5b
Rotation with manure (alfalfa–corn–wheat)	24.2b	58.9b	16.9a	2.2ab
Rotation without manure (meadow–corn–wheat)	41.0a	43.5c	15.5a	2.9a
No-till rotation (corn–hay)	36.3a	47.8c	15.9a	2.4ab
LSD (0.05)	7.3	6.7	3.3	1.4

Figures within a column with the same letter are statistically similar ($P = 0.05$).

Table 5
Land use and management effects on textural properties of a Ravenna-Canfield silt loam in Stark County farms

Treatment	Particle size (%)			Particulate organic matter (%)
	Sand	Silt	Clay	
0–5 cm				
Wooded control	26.7b	60.3a	13.1b	0–5
Rotation without manure	39.7ab	43.4b	16.9a	7.7a
Rotation with poultry manure	41.8a	46.9ab	11.4b	2.5b
LSD (0.05)	13.8	14.6	3.8	2.6b
5–10 cm				
Wooded control	30.8b	55.7a	13.5a	4.6a
Rotation without manure	34.4b	48.2b	17.4a	1.5b
Rotation with poultry manure	43.3a	43.8b	12.8a	2.0b
LSD (0.05)	8.0	6.9	4.6	2.5

Figures within a column with the same letter are statistically similar ($P = 0.05$).

among cultivated soils may be due to the benefit of high residue incorporation in the RCF soil compensating for the advantage of manuring in the RPM soil.

3.3. Aggregate size and soil organic carbon concentration

The wooded control sites in Stark and Geauga Counties generally have higher SOC concentration in aggregates (C_{ag}) than in cultivated soils, and aggregates from 0 to 5 cm depth have higher SOC concentration than those from 5 to 10 cm depth. Macroaggregates (4.75–8.00 mm) have higher C_{ag} than smaller aggregates (0.5–2.0 mm) (Figs. 5–8).

In Geauga County, soil treated with DM generally has higher C_{ag} than other cultivated treatments, especially so in >2 mm aggregates (Figs. 5 and 6). The CC treatment has less difference in C_{ag}

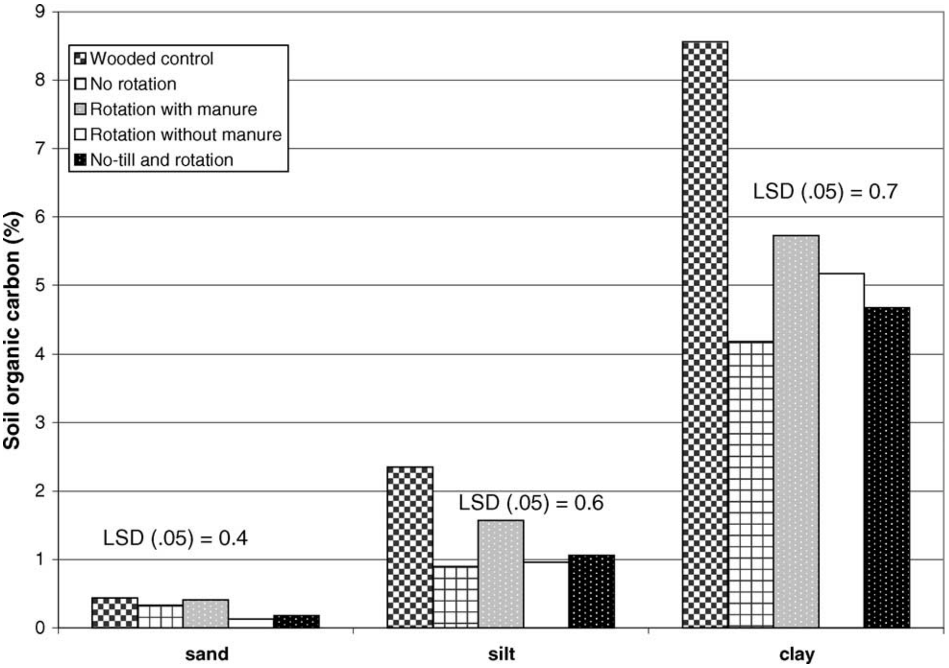

Fig. 1. Distribution from 0 to 5 cm of soil organic carbon with particle size for different land use and management treatments on a Geauga County farm.

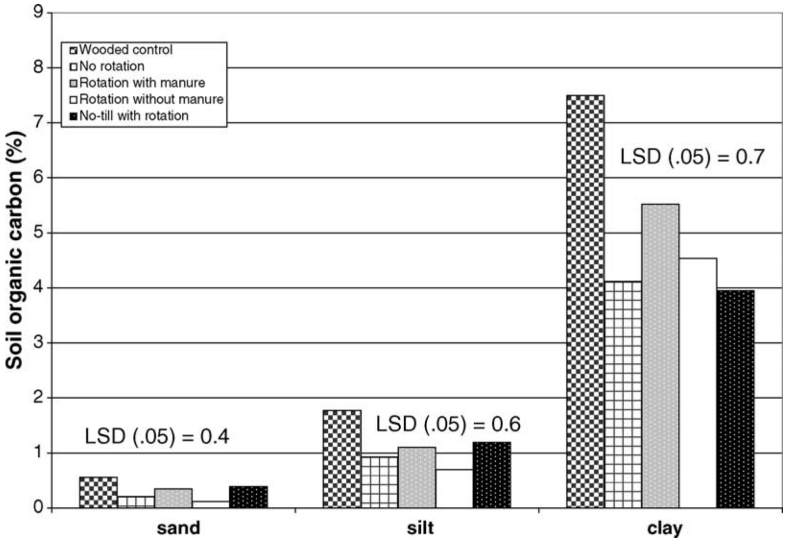

Fig. 2. Distribution from 5 to 10 cm of soil organic carbon (C%) with particle size for different land use and management treatments on a Geauga County farm.

concentration between aggregate size groups than other treatments, particularly in the 0–5 depth (Tables 6 and 7). These trends may be related to the lack of variability in C source and disturbances from cultivation, which disrupt aggregates and expose the C_{ag} to more rapid decomposition (Six et al., 2000).

In Stark County, there was no difference in C_{ag} between depths or between the cultivated treatments (Fig. 6). Smaller aggregates (0.25–0.5 mm) had less C_{ag} than larger aggregates. The lack of difference between manured and unmanured treatments may reflect the cropping history. The manured field was

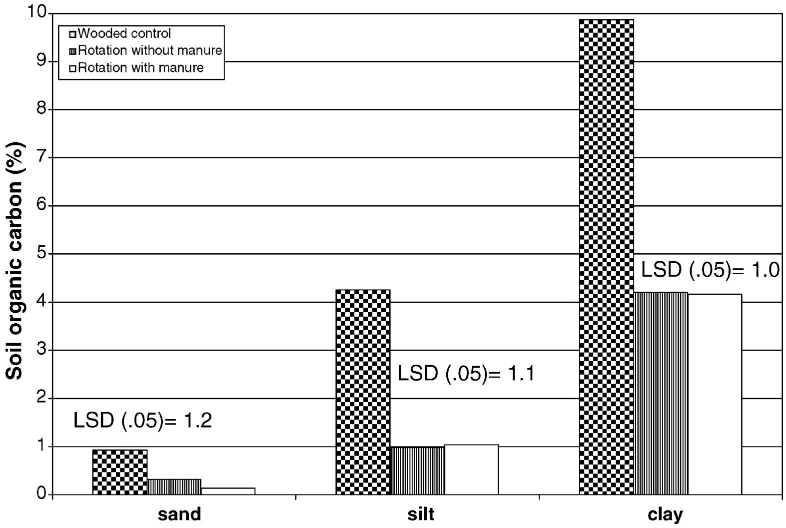

Fig. 3. Distribution from 0 to 5 cm of soil organic carbon (C%) with particle size for different land use and management treatments on Stark County farms.

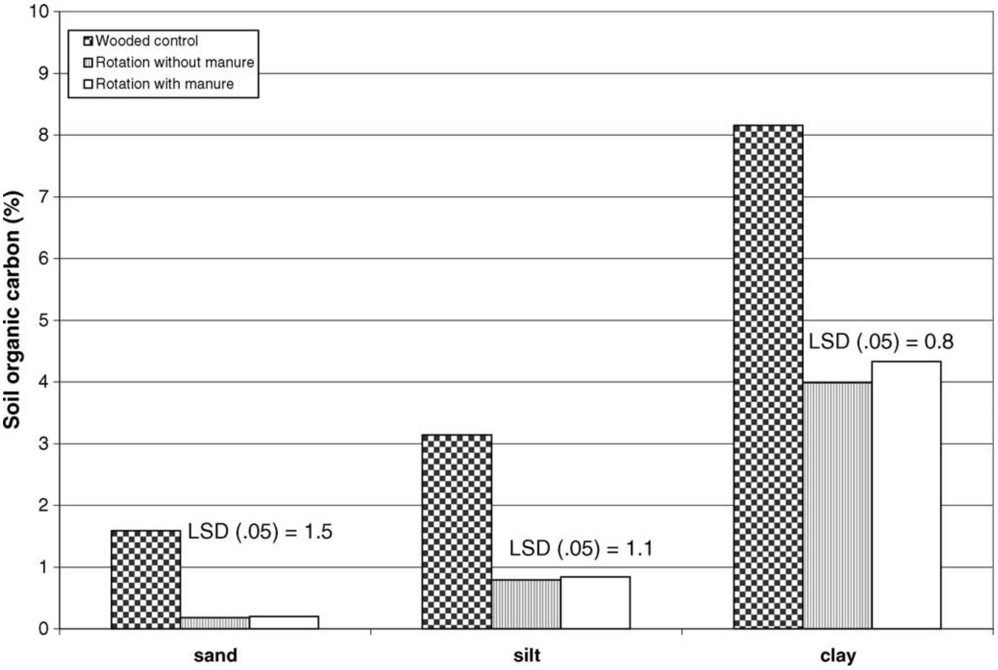

Fig. 4. Distribution from 5 to 10 cm of soil organic carbon (C%) with particle size for different land use and management treatments on Stark county farms.

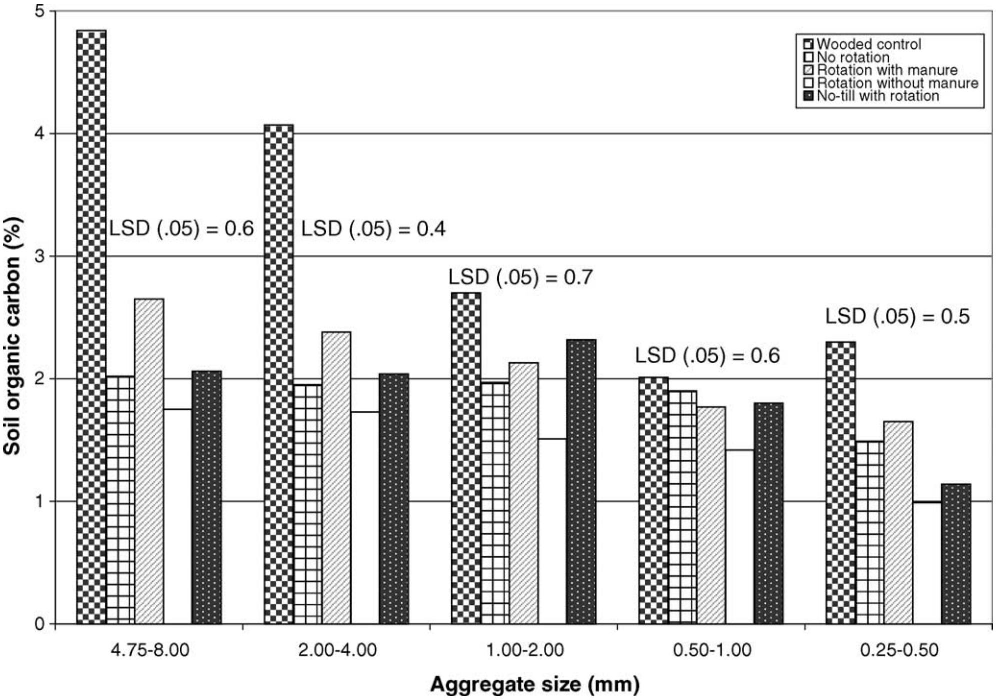

Fig. 5. Distribution from 0 to 5 cm of soil organic carbon (C%) with aggregate sizes for different land use and management treatments on a Geauga County farm.

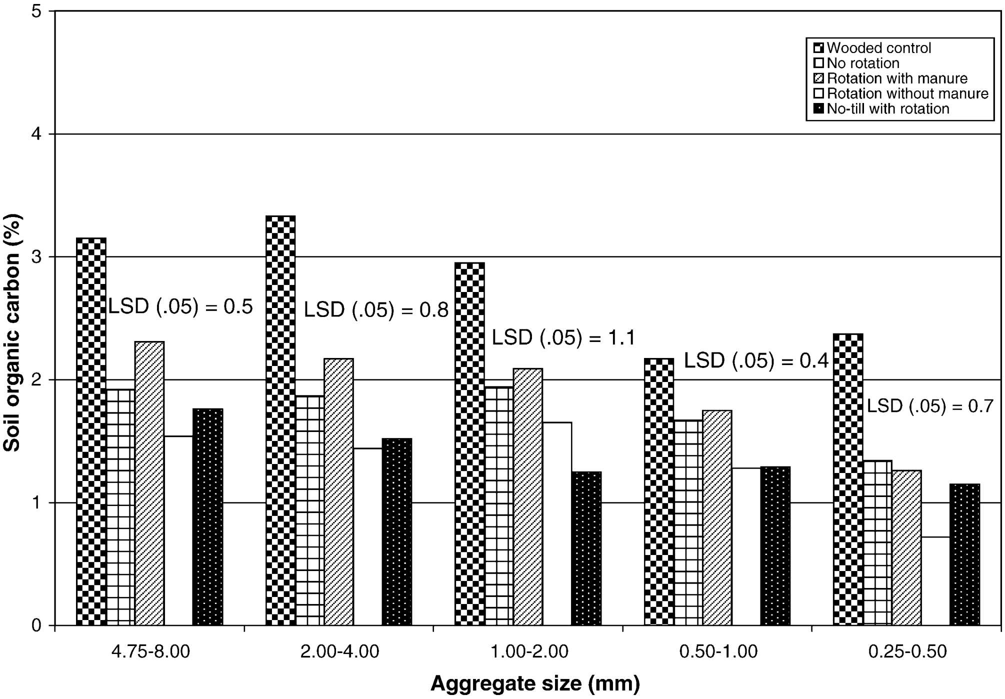

Fig. 6. Distribution from 5 to 10 cm of soil organic carbon (C%) with aggregate sizes for different land use and management treatments on a Geauga County farm.

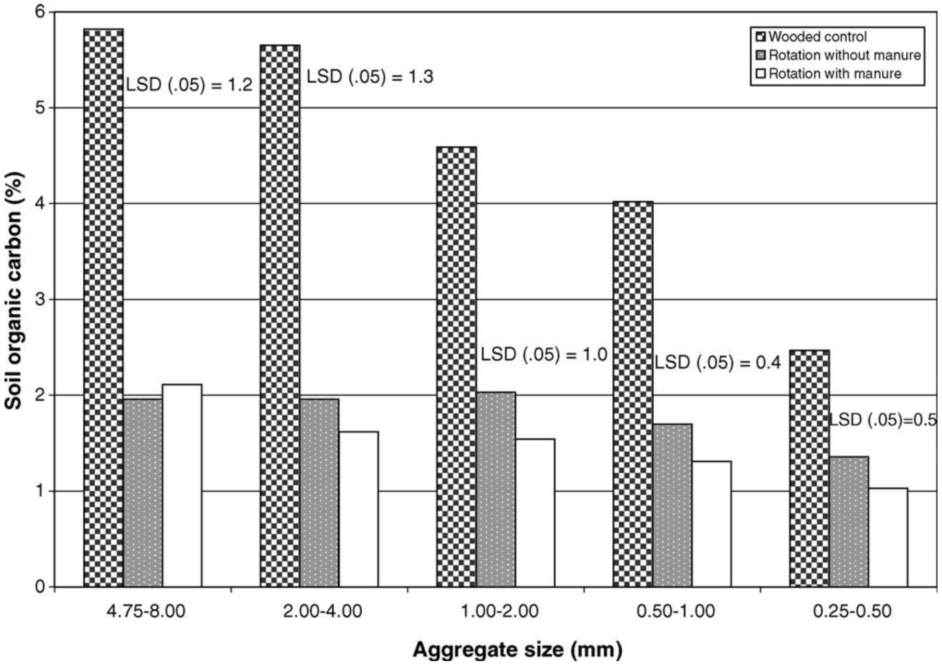

Fig. 7. Distribution from 0 to 5 cm of soil organic carbon (C%) with aggregate sizes for different land use and management treatments on Stark County farms.

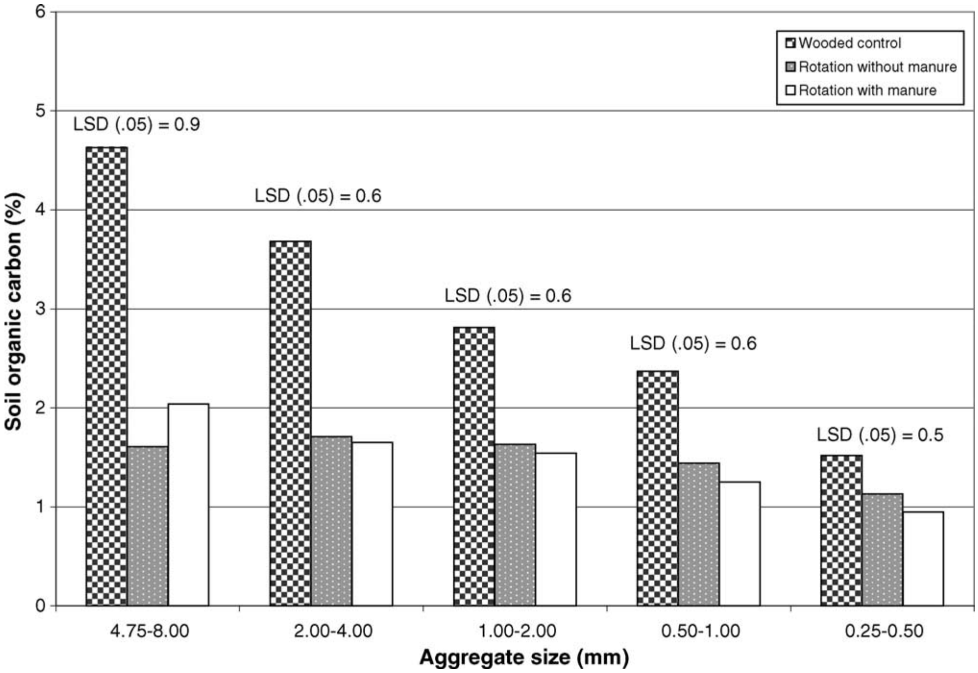

Fig. 8. Distribution from 5 to 10 cm of soil organic carbon (C%) with aggregate sizes for different land use and management treatments on Stark County farms.

grown to corn and residues in the field were from the previous years soybean. Soybeans leave low amount of residues and of different composition than corn (Martens, 2000b). The unmanured soil was grown to soybean, through the previous year's corn residues. The SOC concentration in the unmanured soil may represent C input from residues while SOC in the manured field may be derived from manure. The manure was applied 2 years before the study, and most of it may have been mineralized by the time soil was sampled (Pare et al., 2000; Aulakh et al., 2000).

Table 6
Land use and management effects on soil organic carbon concentration (C%) in a Canfield silt loam in a Geauga County farm

Aggregate size (mm)	Wooded control	No rotation (continuous corn)	Rotation with manure (alfalfa–corn–wheat)	Rotation no manure (meadow–corn–wheat)	No-till rotation (corn–hay)	LSD (0.05)
0–5 cm						
4.75–8.00	4.84a	2.02c	2.65b	1.75c	2.06c	0.6
2.00–4.75	4.07a	1.95c	2.38b	1.73c	2.04bc	0.4
1.00–2.00	2.70a	1.97bc	2.13abc	1.51c	2.32ab	0.7
0.50–1.00	2.01a	1.90a	1.77a	1.42a	1.80a	0.6
0.25–0.50	2.30a	1.49bc	1.65b	0.99c	1.14bc	0.5
5–10 cm						
4.75–8.00	3.15a	1.92bc	2.31b	1.54c	1.76c	0.5
2.00–4.75	3.33a	1.87b	2.17b	1.44b	1.52b	0.8
1.00–2.00	2.95a	1.94ab	2.09ab	1.65b	1.25b	1.1
0.50–1.00	2.17a	1.67bc	1.75b	1.28c	1.29c	0.4
0.25–0.50	2.37a	1.34b	1.26b	0.72b	1.15b	0.7

Figures within a row with the same letter are statistically similar ($P = 0.05$).

Table 7
Land use and management effects on soil organic carbon concentration (C%) in a Ravenna-Canfield silt loam in Stark County farms

Aggregate size (mm)	Wooded control	Rotation without manure	Rotation with poultry manure	LSD (0.05)
0–5 cm				
4.75–8.00	5.82a	1.96b	2.11b	1.2
2.00–4.75	5.65a	1.96b	1.62b	1.3
1.00–2.00	4.59a	2.03b	1.54b	1.0
0.50–1.00	4.02a	1.70b	1.31b	0.4
0.25–0.50	2.47a	1.36b	1.03b	0.5
5–10 cm				
4.75–8.00	4.63a	1.61b	2.04b	0.9
2.00–4.75	3.68a	1.71b	1.65b	0.6
1.00–2.00	2.81a	1.63b	1.54b	0.6
0.50–1.00	2.37a	1.44b	1.25b	0.6
0.25–0.50	1.52a	1.13ab	0.95b	0.5

Figures within a row with the same letter are statistically similar ($P = 0.05$).

4. Conclusions

Uncultivated soils have higher WSA and higher C_{ag} concentrations than cultivated soils. The C_{ag} concentration was higher in 0–5 cm than 5–10 cm depth, and in macroaggregates compared to microaggregates. The SOC concentration was also higher in clay-sized compared to sand- and silt-sized particles. Cultivation decreases aggregation through disturbances associated with tillage, making biomass more available to decomposition and erosion. Cultivated soils have lower POM and higher sand concentrations, which contribute to lower SOC retention. The SOC associated with dispersed clay is more susceptible to decomposition than that encapsulated within aggregates. Soils managed with conservation tillage practices such as no-till, manuring and rotation had high aggregation and SOC concentration compared to soils without conservation management. The effects of these practices are interactive and difficult to separate. The benefits of manuring may offset reduced amounts of residues from previous crops while those of high residues return may compensate for the use of chemical fertilizer rather than manure. In Geauga County the lack of tillage in recent years and high C input from residues and extensive rooting from grass and alfalfa for the three rotations may mask other benefits of past manuring. This study suggests that the combination of conservation tillage, increasing C inputs and increasing the complexity of the agricultural system improves aggregation and SOC concentration.

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References

Aoyama, M., Angers, D.A., N'Dayegamiye, A., Bissonnette, N., 2000. Metabolism of C-13-labeled glucose in aggregates from soils with manure application. Soil Biol. Biochem. 32, 295–300.

Aulakh, M.S., Khera, T.S., Doran, J.W., 2000. Mineralization and denitrification in upland, nearly saturated and flooded subtropical soil – II Effect of organic manures varying in N content and C: N ratio. Biol. Fertil. Soils 31, 168–174.

Campbell, C.A., Zentner, R.P., Liang, B.C., Roloff, G., Gregorich, E.C., Blomert, B., 2000. Organic C accumulation in soil over 30 years in semiarid southwestern Saskatchewan – effect of crop rotations and fertilizers. Can. J. Soil Sci. 80, 179–192.

Chan, K.Y., Heenan, D.P., 1996. The influence of crop rotation on soil structure and soil physical properties under conventional tillage. Soil Tillage Res. 37, 113–125.

Eivazi, F., Bayan, M.R., Schmidt, K., 2003. Select soil enzyme activities in the historic Sanborn Field as affected by long-term cropping systems. Commun. Soil Sci. Plant Anal. 34, 2259–2275.

Follett, R.F., 2001. Soil management concepts and carbon sequestration in cropland soils. Soil Tillage Res. 61, 77–92.

Franzluebbers, A.J., 2002. Water infiltration and soil structure related to organic matter and its stratification with depth. Soil Tillage Res. 66, 197–205.

Graham, M.H., Haynes, R.J., Meyer, J.H., 2002. Soil organic matter content and quality: effects of fertilizer applications, burning and trash retention on a long-term sugarcane experiment in South Africa. Soil Biol. Biochem. 34, 93–102.

Hao, Y., Lal, R., Owens, L.B., Izaurralde, R.C., Post, W.M., Hothem, D.L., 2002. Effect of cropland management and slope position on soils organic carbon pool at the Appalachian Experimental Watersheds. Soil Tillage Res. 68, 133–142.

Hao, X.Y., Chang, C., Travis, G.R., Zhang, F.R., 2003. Soil carbon and nitrogen response to 25 annual cattle manure applications. J. Plant Nutr. Soil Sci. -Zeitschrift Fur Pflanzenernahrung und Bodenkunde 166, 239–245.

Haynes, R.J., Beare, M.H., 1997. Influence of six crop species on aggregate stability and some labile organic matter fractions. Soil Biol. Biochem. 29, 1647–1653.

Haynes, R.J., Naidu, R., 1998. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. Nutr. Cycl. Agroecosys. 51, 123–137.

Hulugalle, N.R., Cooper, J., 1994. Effect of crop-rotation and residue management on properties of cracking clay soils under irrigated cotton-based farming systems of New-South-Wales. Land Degrad. Rehabil. 5, 1–11.

Hussain, I., Olson, K.R., Ebelhar, S.A., 1999. Long-term tillage effects on soil chemical properties and organic matter fractions. Soil Sci. Soc. Am. J. 63, 1335–1341.

Kay, B.D., 1998. Soil structure and organic carbon: a review. In: Lal, R., Kimble, J.M., Follett, R.F., Stewart, B.A. (Eds.), Soil Processes and the Carbon Cycle. CRC Press, Boca Raton, FL, pp. 169–197.

Kemper, W.D., Rosenau, R., Nelson, S., 1985. Gas displacement and aggregate stability of soils. Soil Sci. Soc. Am. J. 49, 25–28.

Kemper, W.D., Rosenau, R., 1986. Aggregate stability and size distribution. In: Page, A.L. (Ed.), Methods of Soil Analysis. Part I. Physical and Mineralogical Methods. Soil Sci. Soc. Am. J., Madison, WI, pp. 425–442.

Khanna, P.K., Ludwig, B., Bauhus, J., O'Hara, C., 2001. Assessment and significance of labile organic c pools in forest soils. In: Lal, R., Kimble, J.M., Follett, R.F., Stewart, B.A. (Eds.), Assessment Methods For Soil Carbon. Lewis Publishers, Boca Raton, FL, pp. 167–182.

Kushwaha, C.P., Tripathi, S.K., Singh, K.P., 2001. Soil organic matter and water-stable aggregates under different tillage and residue conditions in a tropical dryland agroecosystem. Appl. Soil Ecol. 16, 229–241.

Lal, R., 2003a. Soil erosion and the global carbon budget. Environ. Int. 29, 437–450.

Lal, R., 2003b. Offsetting global CO_2 emissions by restoration of degraded soils and intensification of world agriculture and forestry. Land Degrad. Dev. 14, 309–322.

Liu, X.B., Han, X.Z., Song, C.Y., Herbert, S.J., Xing, B.S., 2003. Soil organic carbon dynamics in black soils of China under different agricultural management systems. Commun. Soil Sci. Plant Anal. 34, 973–984.

Martens, D.A., 2000a. Plant residue biochemistry regulates soil carbon cycling and carbon sequestration. Soil Biol. Biochem. 32, 361–369.

Martens, D.A., 2000b. Management and crop residue influence soil aggregate stability. J. Environ. Qual. 29, 723–727.

Martens, D.A., Frankenberger Jr., W.T., 1992. Modification of infiltration rates in an organic-amended irrigated soil. J. Agron. 84, 707–717.

Munkholm, L.J., Schjonning, P., Debosz, K., Jensen, H.E., Christensen, B.T., 2002. Aggregate strength and mechanical behaviour of a sandy loam soil under long-term fertilization treatments. Eur. J. Soil Sci. 53, 129–137.

Nelson, D.W., Sommers, L.E., 1982. Total carbon organic carbon and organic matter. In: Page, A.L., Miller, R.H., Keeney, D.R. (Eds.), Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties, second ed. Am. Soc. Agron., Madison, WI, pp. 539–594.

Nyamangara, J., Piha, M.I., Kirchmann, H., 1999. Interactions of aerobically decomposed cattle manure and nitrogen fertilizer applied to soil. Nutr. Cycl. Agroecosys. 54, 183–188.

Pare, T., Dinel, H., Moulin, A.P., Townley-Smith, L., 1999. Organic matter quality and structural stability of a Black Chernozemic soil under different manure and tillage practices. Geoderma 91, 311–326.

Pare, T., Dinel, H., Schnitzer, M., 2000. Carbon and nitrogen mineralization in soil amended with non-tabletized and tabletized poultry manure. Can. J. Soil Sci. 80, 271–276.

Puget, P., Chenu, C., Balesdent, J., 1995. Total and young organic-matter distributions in aggregates of silty cultivated soils. Eur. J. Soil Sci. 46, 449–459.

Raimbault, B.A., Vyn, T.J., 1991. Crop rotation and tillage effects on corn growth and soil structural stability. Agron. J. 83, 979–985.

Rutledge, E.M., Wilding, L.P., Elfield, M., 1967. Automated particle size-separation by sedimentation. Soil Sci. Soc. Am. Proc. 31, 287–288.

Salinas Garcia, J.R., Hons, F.M., Matocha, J.E., Zuberer, D.A., 1997. Soil carbon and nitrogen dynamics as affected by long-term tillage and nitrogen fertilization. Biol. Fertil. Soils 25, 182–188.

SAS Institute Inc., 1989. SAS/STAT® User's Guide, Version 6, 4th ed., vol. 1. SAS Institute, Inc., Cary, NC.

Schjonning, P., Elmholt, S., Munkholm, L.J., Debosz, K., 2002. Soil quality aspects of humid sandy loams as influenced by organic and conventional long-term management. Agric. Ecosyst. Environ. 88, 195–214.

Six, J., Elliott, E.T., Paustian, K., 2000. Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. Soil Biol. Biochem. 32, 2099–2103.

Traore, O., Groleau-Renaud, V., Plantureux, S., Tubeileh, A., Boeuf-Tremblay, V., 2000. Effect of root mucilage and modelled root exudates on soil structure. Eur. J. Soil Sci. 51, 575–581.

Unger, P.W., 1997. Management-induced aggregation and organic carbon concentrations in the surface layer of a Torrertic Paleustoll. Soil Tillage Res. 42, 185–208.

USDA, 1971. Soil survey of Stark County, Ohio. Soil Conservation Service.

USDA, 1982. Soil survey of Geauga County, Ohio. Soil Conservation Service.

West, T.O., Post, W.M., 2002. Soil organic carbon sequestration rates by tillage and crop rotation: a global data analysis. Soil Sci. Soc. Am. J. 66, 1930–1946.

Whalen, J.K., Chang, C., 2002. Macroaggregate characteristics in cultivated soils after 25 annual manure applications. Soil Sci. Soc. Am. J. 66, 1637–1647.

Yoder, R.E., 1936. A direct method of aggregate analysis and a study of the physical nature of erosion losses. J. Am. Soc. Agron. 28, 337–351.

Youker, R.E., McGuinness, J.L., 1956. A short method of obtaining mean weight diameter values of aggregate analyses of soils. Soil Sci. 83, 291–294.