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Aggregate distribution and soil organic matter under different tillage systems for vegetable crops in a Red Latosol from Brazil

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Abstract

Several management systems can improve soil productivity. By studying aggregate stability it is possible to quantify whether or not the management is ameliorating the natural soil properties and the land capability for agriculture. The effect of three tillage systems on the stability of soil aggregates and soil organic carbon was studied in comparison to reference plots with grass and bare soil. Samples were collected at the Pesagro Experimental Research Station in Paty do Alferes, state of Rio de Janeiro, Brazil, from an experiment that has been carried out from 1995 to 2001, on a Dystrophic Red Latosol (Typic Haplorthox). Aggregate size distribution mean weight diameter, geometric mean diameter of the aggregates, and total organic carbon in each aggregate size fraction were determined. The proportion of aggregates with diameter ≥2 mm appeared to be a suitable indicator of the influence of tillage systems on aggregation. At a depth of 0–5 cm, aggregates ≥2 mm were 50% of soil under no-tillage, which was greater than under animal traction (35%) and conventional tillage (30%). Total organic carbon concentration was greater under no-tillage (19 g kg^{-1}) than under conventional tillage (11 g kg^{-1}) at a depth of 0–5 cm, but not significantly different (average 13 g kg^{-1}) at a depth of 5–10 cm. Soil exposure with tillage and lack of residue inputs caused declines in aggregation and organic carbon, both of which make soil susceptible to erosion. Adoption of no-tillage led to a decline in aggregation compared with grass reference, but did significantly alter soil organic concentration, suggesting it was a valuable conservation practice for vegetable production on sloping soils.

Keywords: No-tillage; Soil aggregation indices; Aggregate-associated carbon; Erosion

1. Introduction

Soil aggregation is important for the resistance of land surfaces to erosion, and it influences the ability of soils to remain productive. Modification of some soil attributes can be used to evaluate the soil physical condition, determining whether a certain soil management for crop production might improve its natural characteristics or the land capability. Soil aggregate distribution has been used as a conservation index for clayey Oxisols, cultivated with wheat (*Triticum aestivum*), corn (*Zea mays*) and soybean (*Glycine max*), in Paraná State (Castro Filho et al., 2002). However, no soil aggregation index has been tested on sloping soils under intense cultivation with vegetable crops.

Soil aggregation may be determined by mean weight diameter (MWD), geometric mean weight diameter (GMD) and aggregate stability (AS, %) index,

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which are obtained by fractioning the soil material into aggregate classes by wet sieving (Kemper and Chepil, 1965). These indices are sensitive to soil management practices and physical conditions. Physical disturbance of soil structure (e.g. through tillage) has resulted in decreasing aggregate stability paralleled by a loss of soil organic matter (SOM) (Elliott, 1986; Beare et al., 1994; Six et al., 2000), indicating a link between SOM and soil aggregate dynamics.

Several models have been proposed in order to correlate aggregate dynamics to a change in SOM. Tisdall and Oades (1982) presented a conceptual, hierarchical model for soil aggregate formation. It describes the association of organic matter with three different soil physical units: silt and clay particles, microaggregates (<250 μm), and macroaggregates (>250 μm). This model was applied by several investigators to explain the often observed accumulation of SOM under no-tillage versus conventional tillage systems (Beare et al., 1994). According to Tisdall and Oades (1982), cultivation causes a reduction in the amount of macroaggregates, but it does not affect microaggregate stability. The organic matter binding microaggregates into macroaggregates has been suggested to be the primary source of organic matter lost when grassland soils are cultivated (Elliott, 1986).

The objective of the study was to compare the effect of tillage systems on aggregation and soil organic carbon on sites cultivated with vegetable crops in the mountainous region of Rio de Janeiro in Brazil.

2. Materials and methods

The research site was initiated in 1995, at the Pesagro, Rio Experimental Research Station, Paty do Alferes County, Rio de Janeiro State (Brazil). Soil at the site was a Dystrophic Red Latosol (Typic Haplorthox) with slope of 30% (Table 1). Annual precipitation averaged 1200 mm, with about 48% from November to January. Average annual temperature was 21 °C, maximum of 24 °C in February and minimum of 16.5 °C in July. Plots with dimensions of 22 m × 4 m were cultivated with a rotation of vegetables, including tomato (*Lycopersicon esculentum*), green pepper (*Capsicum annuum*) and beans (*Phaseolus vulgaris*). At the time of sampling (1998) the plots were grown with green pepper, and the same cropping sequence was followed in all cultivated plots.

The area was previously under grass coverage (*Panicum maximum* L.) without management. Treatments consisted of three planting systems: conventional tillage (CT), contour tillage with animal traction (AT), and no-tillage (NT). Also two reference treatments were included: with grass coverage (GR) and bare soil (NC). All five treatments (tillage and references) were arranged in a randomized block design, with three repetitions. In this region CT consists of one disc plowing downhill, followed by one light disc harrowing; tillage depth was near 0.20 m and harrowing about 0.10–0.15 m; the crop residues were removed or burned prior to the next rotation cycle. On the AT plot contour animal traction was used; the crop residue was left on the soil; grass barriers were planted every 7 m. For NT the seedlings were planted directly without tillage; the plot had the maximum residue coverage.

Three undisturbed soil samples (near field capacity) were collected to perform aggregate distribution in the 0–5 and 5–10 cm depths in each treatment in the summer of 1998. Samples were pre-sieved using an 8 and 4 mm sieve. Soil aggregates retained on the 4 mm sieve were separated by wet sieving (Kemper and Chepil, 1965). The samples (25 g) were prewetted with an atomizer. Aggregates were then sieved for 15 min (35 rpm), using five sieves of 2, 1, 0.5, 0.25 and 0.105 mm mesh. The stroke length of the sieving apparatus was 3.5 cm. The material retained on

Table 1
Characteristic horizon's attributes of the Dystrophic Red Latosol (Typic Haplorthox)

Horizon	Depth (cm)	pH (H_2O)	Clay ($g\,kg^{-1}$)	Organic C ($g\,kg^{-1}$)	Cations[a] ($cmol_c/kg$)	CEC[b] ($cmol_c/kg$)
Ap	0–22	5.8	380	11.3	2.8	8.7
Bw2	68–92	4.8	450	3.1	0.9	3.1

[a] Sum of Ca, Mg, K and Na.
[b] CEC = cations + Al + H.

each sieve was removed and oven dried at 105 °C for 24 h. After recording aggregate weights in each size fraction for each soil sample, a portion of the aggregates was finely ground for total C analysis, using the Walkley–Black method. Soil moisture content of the samples was determined by weighing the soil prior and after oven drying at 105 °C.

The aggregate indices were calculated according to the following formulas:

$$\mathrm{MWD} = \sum x_i y_i$$

where y_i is the proportion of each size class with respect to the total sample and x_i the mean diameter of the size class (mm).

Geometric mean diameter was calculated as follows:

$$\mathrm{GMD} = \exp\left\{\frac{\sum w_i \ln x_i}{\sum w_i}\right\}$$

where w_i is the weight of the aggregates of each size class (g) and $\ln x_i$ the natural logarithm of the mean diameter of size classes.

Results were analyzed by the SAS statistical package (SAS Institute, 1990). The F-test ($P < 0.05$) was applied to determine the significance of main effects from ANOVA. Variables that were significant had treatment means separated using the Tukey's test.

3. Results and discussion

Cation exchange capacity was low in this soil (Table 1), which characterizes the low natural fertility of Oxisols in the mountainous region of Rio de Janeiro. Therefore, the sustainable management of these soils is dependent on conserving and increasing SOM and protecting soil from erosion (Anjos et al., 1998).

Distribution of aggregates in the 0–5 and 5–10 cm layers (Fig. 1) indicated the highest concentration in the ≥2.0 mm diameter class for all treatments. The fraction of soil as aggregates ≥2.0 mm was greatest on the grass area, followed by NT, and lowest for NC. In the 0–5 cm layer, there was no significant difference between AT, CT and NC aggregates ≥2.0 mm. The benefits to soil aggregation with NT especially, favored larger aggregates in the top few centimeters of soil, as was also observed by Carpenedo and Mielnickzuk (1990), Campos et al. (1995), and Mrabet et al. (2001). Aggregates were distributed mainly in the smaller diameter classes in the treatments with less residue coverage and more intensively mechanically disrupted by tillage (NC and CT). Consequently, these treatments were more likely to have soil loss by erosion.

Soil organic C concentration was relatively uniform across aggregate size classes, although values tended to be greater in the >2.00 mm class (Fig. 2). Among treatments, soil organic C concentration was typically lower under bare soil than under other treatments in all size classes.

Organic matter is considered one of the main agents favoring soil aggregation. Part of the aggregate size variation, and therefore, the aggregation indices in tropical soils can be attributed to variations in SOM (Castro Filho, 1988).

The decline in the size of aggregates with CT could be credited to mechanical disruption of macroaggregates, which may have exposed SOM previously protected against oxidation. The lack of residue coverage, promoting the erosion of fine clay and organic matter particles (Schick et al., 2000a,b), would likely have been responsible for the lowest organic carbon concentration and aggregate stability under NC. The highest organic carbon concentration in GR may have been related to the higher input and renovation of aerial and root biomass (Silva and Mielniczuk, 1997). Roots greatly influence the formation and stabilization of soil aggregates (Silva and Mielniczuk, 1997). The result suggests that conversion from grass pasture to a vegetable rotation system under CT may result in high loss of SOM and poor aggregation. Biomass inputs under vegetable cropping were not sufficient to maintain C with CT, but were with NT.

Carbon concentration of the 0–5 cm layer was 39% higher in NT than in CT (Table 2). There was no statistical difference between NT and CT in the 5–10 cm depth. Muzilli and Resende (1983) found that after 5 years of comparison, SOM was slightly higher for NT compared to CT, but only at the 0–5 cm depth. Castro Filho et al. (2002) observed that the tendency for SOM under NT is to concentrate near the surface, while in CT systems SOM is more uniformly distributed. Sá et al. (2001), studying SOM dynamics in a Brazilian Oxisol, under corn/wheat/soybean rotation, observed a significant increase in soil or-

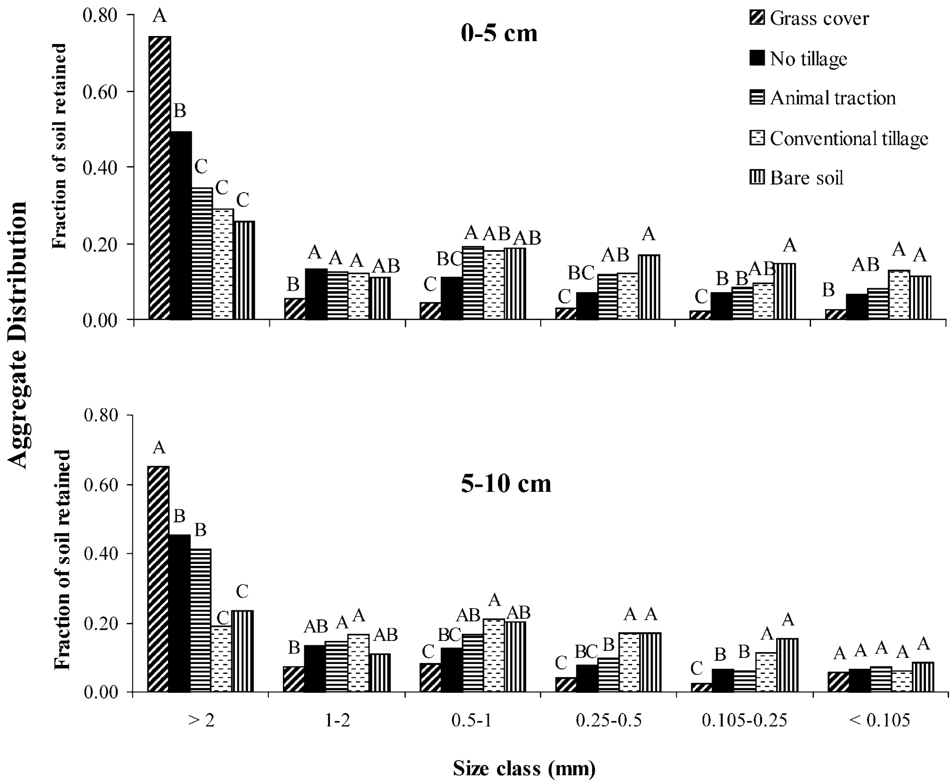

Fig. 1. Water-stable aggregate size distribution in the 0–5 and 5–10 cm layers as a function of tillage systems and reference plots. Means within a size class followed by the same upper case letters do not differ ($P < 0.05$).

ganic carbon concentration in the upper 10 cm layer in soils under NT compared with soils under natural vegetation (subtropical prairie and subtropical gallery forest) and long term conventional tillage (22 years). The authors explained the effect by the high crop residue input and the lack of soil disturbance on NT. For vegetable production the amount of SOM derived from crop residue is typically lower, which partially explains the lack of differences among tillage systems in the organic carbon content at the 5–10 cm layer.

There was a significant difference in the MWD and GMD values between treatments at 0–5 and 5–10 cm depth, with highest values for GR and NT (Table 3). The smallest GMD was in CT and NC, indicating a

Table 2
Total organic carbon concentration as a function of the tillage systems and reference plots

Tillage systems and reference plots	Organic carbon ($g\,kg^{-1}$)	
	0–5 cm	5–10 cm
Grass coverage	21.8 A	17.5 A
No-tillage	18.5 A	14.6 A
Animal traction	16.8 AB	15.7 A
Conventional tillage	11.4 BC	12.2 AB
Bare soil	6.9 C	7.2 B

Means within a depth followed by the same upper case letters do not differ ($P < 0.05$).

Table 3
Mean weight diameter and geometric mean diameter—interactions between treatments and sampling depth

Tillage systems and reference plots	MWD (mm)		GMD (mm)	
	0–5 cm	5–10 cm	0–5 cm	5–10 cm
Grass coverage	4.2 A	3.7 A	1.1 A	1.1 A
No-tillage	3.0 B	2.8 B	1.0 B	1.0 B
Animal traction	2.2 C	2.6 B	1.0 C	1.0 B
Conventional tillage	2.0 C	1.5 C	1.0 C	0.9 C
Bare soil	1.7 C	1.6 C	0.9 D	0.9 C

Means within a depth followed by the same upper case letters do not differ within the column ($P < 0.05$).

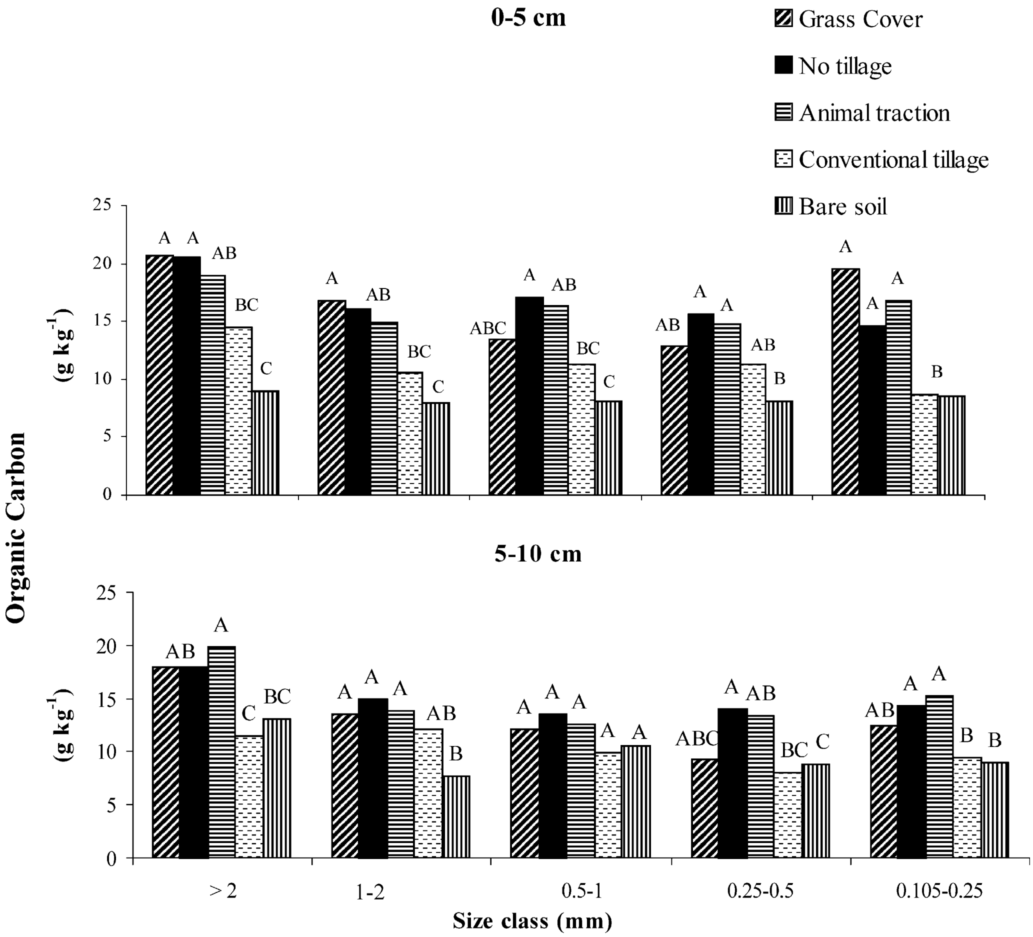

Fig. 2. Influence of the tillage systems and reference plots on organic carbon content in the aggregate size fractions. Means within a size class followed by the same upper case letters do not differ ($P < 0.05$).

greater soil loss potential, which would reduce further the soil fertility and sustainability of vegetable production on these soils. Results from MWD and GMD were consistent with those of aggregates ≥2 mm.

4. Conclusions

The fraction of soils as ≥2 mm was a suitable discriminator of tillage systems. Among the tillage systems, aggregate distribution indices were greater for NT than CT. However, the reference plot with grass coverage had the highest indices for aggregation, total organic carbon and carbon concentration in the aggregate size classes.

Carbon concentration was significantly greater under NT than under CT in both whole soil and aggregate fractions. Carbon was more concentrated in the surface (0–5 cm) under NT, while the distribution was more uniform under CT.

Soil disruption by mechanical tillage and lack of conservation practices caused a reduction in total organic carbon concentration and soil aggregation, indicating greater potential for soil erosion.

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