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Tillage systems effects on soil carbon stock and physical fractions of soil organic matter

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ABSTRACT

Changes in soil management and land use influence soil organic matter (SOM) turnover through changes in quantity and quality of plant residues entering the soil, their seasonal and spatial distribution, the ratio between above- and bellow-ground inputs and through changes in soil disturbance. We hypothesized that the sequestered C is stored mainly in the mineral associated fraction (C associated in sand, silt and clay fraction). The objective of this study was to evaluate the C stock and stabilization in a tropical Dystrophic Red Latosol (Typic Haplortox) (Paty do Alferes, Brazil) subjected to 6-years soil tillage systems and soil cover. Treatments included no-tillage (NT), animal traction (AT) and conventional tillage (CT). Two additional treatments were evaluated: grass coverage (GC) and bare soil (BS). After six years crop, soil C stock in the 0–10 cm layer was higher in NT than in CT (17.6 vs. 12.3 Mg ha^{-1}, $P < 0.05$). It resulted an increase of 5.3 Mg C ha^{-1} in NT when comparing to CT. In NT, most of the C accumulation compared to CT occurred in the mineral associated fraction. Although, only the C associated in sand fraction was statistically different (6.7 vs. 1.2 g kg^{-1} soil, $P < 0.05$). GC had the highest C sequestration and C and N associated in the mineral fraction (14.9 g C kg^{-1} and 5.1 g N kg^{-1}) in the 0–5 cm depth. For all treatments, most of the soil organic C was in the heavy fraction (> 55%). GC incorporated to soil annually 0.6 Mg C ha^{-1}. C associated with sand fractions was the most sensible mineral associated C fraction compared to C in silt and clay fraction, and can be used as a suitable soil quality indicator for sustainable use.
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1. Introduction

Plants are the main source of C to soils through tissue residues or via root exudates and symbiotic fungi (Clemmensen et al., 2013). On balance, nearly all the C that enters soil as plant residues each year either decomposes and returns to the atmosphere or is leached from soils within a few decades to centuries. The rate of accumulation and loss of soil C are estimated from two kinds of information: direct observation of change in the amount of organic matter and inferences based on age measured by radiocarbon (Trumbore and Czimczik, 2008). Soil C can accumulate and be lost at intermediate rates (0.1 to 10 Mg C ha year^{-1}). These rates vary a lot and reflect differences in the dominant process contributing to stabilization of SOM.

By stabilization, Sollins et al. (1996) mean a decrease in the potential for SOM loss by respiration, erosion or leaching. Three main mechanisms of organic matter stabilization in soils have been considered (Sollins et al., 1996; Von Lutzow et al., 2008): (i) recalcitrance of organic compounds at the molecular level; (ii) organo-mineral interaction on the surface of oxides and phyllosilicates; and (iii) physical protection in soil aggregates against decomposers. The first mechanism is no longer seen as the dominant one and the main attention turned to physical protection and organo-mineral associated interactions (Kleber et al., 2011; Kogel-Knaber and Kleber, 2012; Conceição et al., 2013).

In this way, soil physical fractionation is a useful tool in studies related to organic matter stabilization by organo-mineral interaction and physical protection. Physical fractionation of SOM has been useful in distinguishing specific carbon pools that are responsive to management, identifying the physical control of organic matter (Collins et al., 1997). Soil physical fractioning separates SOM with different size or density fractions characterized by different composition and stability as "free light fraction" present within and between aggregates of soil and "heavy organic matter"

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or "mineral associated fraction" (C associated with clay, silt, and sand fraction) (Christensen, 2000). Physical protection of light fraction and its role in aggregate formation and stabilization may be crucial in regulation the proportion of new SOM that is further transformed and stabilized in clay and silt fractions. Organic matter associated with soils minerals consists mainly by microbial tissues or metabolites that are stabilized by organo-mineral interaction via adsorption processes (Kleber et al., 2011). C associated with minerals show significantly longer turnover times, suggesting protection by minerals association and it might be assumed that the preferential storage in fine fractions resulted in a long-term carbon storage.

There are many investigations trying to understand the role that tillage systems play on SOM stabilization An accumulation of SOM under no-tillage (NT) compared to conventional tillage (CT) provides important improvements in soil quality and carbon stabilization. There are mechanisms by which minimum tillage increases SOM accumulation, for example, reduced soil disturbance and redistribution of residues, "the physical protection". Increases in aggregation concomitant with increases in organic C have been observed in NT systems (Six et al., 2000; Pinheiro et al., 2004). Soil tillage has been found to induce a loss of C-rich in macroaggregates (>250 μm) and a gain of C-depleted in microaggregates (<250 μm) (Six et al., 2000).

In an evaluation of the dynamics of SOM within particle size fractions of a clayey Typic Haplorthox from Brazil, Torben et al. (1992) suggested that size fractionation of organo-mineral separates fractions encompass distinct compartments of C with varying susceptibility to biological decomposition. Freitas et al. (2000) in the Cerrado region of Brazil used physical fractionation of SOM and observed more C content in sand fraction in soils under NT than CT. The objective of this study was to evaluate the C stock and stabilization in a tropical Dystrophic Red Latosol (Typic Haplortox) (Paty do Alferes, Brazil) subjected to 7-year soil tillage systems and soil cover.

2. Materials and methods

A field experiment was performed in 1995 at the Pesagro-Rio Experimental Research Station, Paty do Alferes county, Rio de Janeiro State, Brazil. Soil at the experimental site is classified as a Dystrophic Red Latosol (Typic Haplortox) with slope of 30% (Table 1). The regional climate is tropical, classified as CWa by Köppen classification system. Annual mean rainfall and temperature are 1200 mm and 21 °C, respectively.

Plots with dimensions of 22 × 4 m were cultivated with a rotation of vegetables, including tomato (*Lycopersicon esculentum*), green pepper (*Capsicum annuum*) and beans (*Phaseolus vulgaris*). The same cropping sequence was followed in all cultivated plots.

The area was previously under degraded pasture (*Panicum maximum L*). Treatments consisted of three tillage systems: (1) conventional tillage (CT) – in this region, CT consists of one disk plowing downhill, followed by one light disk harrowing; tillage depth was near 0.20 m and harrowing about 0.10–0.15 m. All crop residues were removed or burned prior to the next rotation cycle; (2) animal traction (AT) – contour tillage with animal traction was used and all crop residue was left on soil surface; (3) no-tillage (NT) – seedlings were planted directly without tillage and left crops residues in soil surface. Two additional control treatments were included as (4) grass coverage – with *P. maximum L* (GR) and (5) bare soil (BS). The experimental design was a randomized block design with five treatments and three replications.

Table 1
Soil chemical properties at the experimental site, in 1998.

Horizon	Depth (m)	pH (H_2O)	Clay (g kg^{-1})	SOM	Cations[a] ($cmol_c$ kg^{-1})	CEC[b]
Ap	0–22	5.8	380	19.5	2.8	8.7
Bw	68–92	4.8	450	5.3	0.9	3.1

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

Three undisturbed soil samples (0–5 and 5–10 cm) were taken after beans harvesting in October 1998, by opening one trench per plot (1.2 m square) for the evaluation of soil bulk density of each depth interval (one replicate from each of the four sides of the trench from the center of each depth interval). The soil samples were taken with Kopeck rings (4.5 cm i.d. and total internal volume of 101 cm^3). The samples were air dried and sieved to pass through a 2 mm sieve. By opening trenches so that soil bulk density of each depth interval could be sampled using Kopeck rings. Bulk density samples were removed from the Kopeck rings, dried at 105 °C, weighed and then discarded.

Soil samples were analyzed for pH (in water), were extracted with a solution of potassium chloride (1 mol L^{-1}) to evaluate exchangeable Al, Ca and Mg (Embrapa, 1997). For the analyses of total C and N, sub-samples were further ground to a fine powder (<0.15 mm) using a roller mill similar to that described by Arnold and Schepers (2004). Total organic carbon (TOC) and total nitrogen (TN) analysis was performed on ~150 mg aliquots of the samples using a total C and N analyzer (LECO model CHN 600, Leco Corp., St. Joseph, MI).

Physical fractionation of SOM was performed following the procedure of Sohi et al. (2001). After all light fractions (free and intra-aggregate) have been removed, the residual material in the tube was considered the "mineral associated fraction" or "heavy fraction (HF)". The HF samples were shaken overnight in 300 ml of deionized water with 0.5 g sodium hexametaphosphate (dispersing agent). Sand fraction (2000–53 μm) was isolated by wet-sieving directly through a 53 μm sieve. Sand fraction was washed from the sieve into pre weighed cups, dried at 60 °C, weighed and finely ground for total C and N determination. The silt + clay suspension was transferred to cylinders placed in a room under controlled temperature (25 °C). Water was added to bring the volume to 1000 ml, the suspension was shaken by hand (30 end over end tumbling) and 100 ml of the suspension was immediately withdrawn. They constituted an aliquot of the entire 0–53 μm fraction (clay + silt). After a settling time of 4 h, 200 ml of the suspension was siphoned (<2 μm aliquot; clay fraction), transferred to pre-weighed flasks, dried at 60 °C, and weighed. Once dried, fractions were finely ground for total C and N determination. C and N contents in silt fraction were obtained by difference (Gavinelli et al., 1995). TOC in these fractions were analyzed with the dry combustion method using an elemental analyzer.

The total C and N stocks in the soil were estimated using the procedure recommended by Ellert and Bettany (1995). If in one plot the soil is compacted more than in another, the profile of former to any specific depth will contain a greater mass of soil. It was assumed that any differential soil compaction between plots was most significant in the surface layers of the profiles so that the C stock were calculated by subtracting the total C content of the extra weight of soil in the deepest (5–10, 30–40 or 80–100 cm for calculation of the stocks to 10, 40 or 100 cm, respectively) layer sampled in each profile as described by Neill et al. (1997).

The reference profile used in this study was the treatment NT. As proposed by Balesdent et al. (1990) any one treatment (preferably that with the lowest soil mass in the profile) can be used to correct the others.

Soil sample was done in 1998, 1999, 2000 and 2001. Soil bulk density, as well as all the chemical properties was monitored in the 1999, 2000 and 2001 years. Soil physical fractionation was done only in 2001 years.

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