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Physical fractionation of soil organic matter under different land use systems

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A sustainable management of soil organic matter is fundamental for the maintenance of the soil productivity. The objective of this study was to evaluate changes in the contents and storage of the fractions of the soil organic matter under different management systems compared to the native vegetation as reference in a Red-yellow Latosol in the southern region of the State of Espírito Santo, Brazil. The applied treatments consisted of four land use systems: native forest, annual crop, perennial crop and pasture. Samples were taken from 0 to 10 cm layer for the physical fractionation of soil organic matter, analyzing the amount of total organic carbon and carbon in the light and heavy fraction determining the storage of carbon in the light and heavy fraction. In the native forest, the amounts and storage of carbon were the highest, both in the light and heavy fraction showing stability in the soil carbon reserve. The light fractions of the soil organic matter are more sensitive to the management of the land use systems than the heavy fraction and total organic carbon.

Key words: Soil tillage, agroecosystems, organic carbon.

INTRODUCTION

The different cultivation systems adopted in farming areas after the removal of the native vegetation, induce alterations in the chemical, physical and biological properties of the soil, depending on the type of crop and adopted cultivation practices, establish a new equilibrium in the soil system. In Brazil historically, many management practices were imported from countries with temperate climate where the tilling of the soil surface layer is a practice that is often fundamental for the success of the farming activity. These practices however, increase the oxygen entry into the soil, favoring decomposition processes of soil organic matter (SOM). In Brazilian, soils which are highly weathered with low fertility and marked acidity; organic matter improves the soil fertility because it is the main soil load matrix and also acts as nutrient reservoir. On the other hand, it is known that in tropical soils, the decomposition of organic matter is five times higher than in temperate regions,

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reinforcing the importance of management practices to maintain or increase the SOM contents (Silva and Machado, 2000).

Research addressing the diverse compartments of the organic matter, as well as their relations with farm management, contributes to the development of strategies for the sustainable use of soils with the aim of reducing the impact of farming activities on the environment (Pinheiro et al., 2004; Rangel et al., 2007). The physical fractionation of SOM has proved promising in the distinction of carbon compartments of the soil subject to the influence of various management systems and in the identification of the mechanisms that physically protect organic matter (Collins et al., 1997), besides characterizing the relations between organic matter and soil aggregation (Guegan et al., 1997; Freixo et al., 2002).

Physical fractionation separates SOM in two main compartments based on the specific densities of the organic fractions: i) light fraction (LF), with density lower than 1.7 g cm^{-3} which is a transitory compartment between plant residues and the stabilized and humified organic matter with a higher C/N relation than that of the soil and representing mostly the smallest fraction of the dead compartment of SOM which encompasses, normally from 2 to 18% of total C and from 1 to 12% of total N of the soil and, ii) heavy fraction (HF) composed of organic matter fixed to the colloids or retained on the soil aggregates which can contain more than 90% of the total soil C (Janzen et al., 1992; Vincent et al., 1996; Rangel et al., 2007).

The LF has proved to be an early indicator of the changes in SOM caused by different uses and management systems. Several solutions are used in its separation but little is known about their effects on the quantity and quality of the extracted fraction. Also, little is known about the possible effects of the separation solution on the posterior qualification of OC (Demolinari et al., 2008). The HF consisted of organic matter in advanced decomposition stages not visually distinguishable, strongly connected to the mineral fraction of the soil constituting primary mineral-organic complexes and containing organic composts of high recalcitrance (Christensen, 2000; Roscoe and Machado, 2002). The HF corresponds to SOM in advanced decomposition stage being more stable and with a longer residence time in soil than the LF (Chistensen, 2000; Souza et al., 2006). The purpose of this study was to evaluate the effects of different land use systems on contents, stocks and fractions of organic carbon of a Yellow Red Latosol in the southern region of the State of Espírito Santo, Brazil.

MATERIALS AND METHODS

This study analyzed samples of a Red-Yellow Latosol from the Federal Institute of Education, Science and Technology of Espírito Santo, campus Alegre, Espírito Santo, Brazil (20º 45' 51" S; 41º 27' 24" W; 131.4 m).

For the evaluation of different land use systems, four neighboring areas were selected and distributed in a homogenous soil strip. The evaluated land use systems were: native forest (NF), annual crop (AC), perennial crop (PC) and pasture (PT). These land use systems were chosen based on the use history and the characteristics of the adopted management systems. The history of the evaluated systems is shown in Table 1.

Soil samples were collected in September in 2012, selecting four 300 m^2 plots per system (15 × 20 m). Fifteen simple samples per land use and plot were collected from the 0 to 10 cm layer, and blended to a composite sample, thus resulting in four composite samples per use system, each one constituting a replication. For the evaluation of soil bulk density, an undisturbed sample per plot was collected from the same layer (0 to 10 cm) with a volumetric ring of 89.53 cm^3, calculating the bulk density of the soil of each system from the average of four replications. In all use systems, before collecting the soil samples, the plant residues on the soil surface were removed.

The composite samples (replications) were packed in plastic bags and sent to the laboratory. For the analysis of organic carbon contents (OC) the samples were air-dried, loosened, ground in a mortar and sieved through a 0.210 mm mesh. The samples for the physical fractionation were air-dried, loosened and sieved through a 2 mm mesh to obtain air-dried soil.

The OC was determined by the method described by Yeomans and Bremner (1988). The light and heavy fractions of the SOM were obtained as described by Anderson and Ingram (1989). The OC content in the light fraction (C-LF) was determined according to the methodology described by Yeomans and Bremner (1988). The OC content in the heavy fraction (C-HF) was obtained by the difference: C-HF = OC - C-LF. Based on the data of the contents of C-LF and OC, the proportion C-LF/OC was calculated by the following formula: (C-LF/OC) x 100. The storage of C-LF and C-HF in the different land use systems was calculated by the following formula: storage of C-LF or C-HF (t ha^{-1}) = content of C-LF or C-HF (g kg^{-1}) x Ds x E/10 in which Ds = soil density (kg dm^{-3}) (average of four replications) and; E = thickness of the soil layer (cm).

The data of the contents of OC, C-LF and C-HF of the relation C-LF/OC and of the storages of C-LF and C-HF were subjected to analysis of variance to test the effects of the land use systems. The means were compared by the Tukey test at 5% using the statistical package SAEG.

RESULTS

The content total of organic carbon (TOC) was altered significantly by the land use systems (Table 2). The highest contents were observed in the NF system and the lowest in AC and PC with TOC contents varying from 14.42 to 8.10 g kg^{-1} in NF and PC, respectively.

In comparison to the NF area, all other management systems reduced the TOC contents indicating an increase in the oxidation rate of the soil TOC under cultivation. In relation to the NF system, the reductions in TOC contents were respectively, 26.7, 43.8 and 9.7%, for the use systems AC, PC, PT.

The results of this work indicate that the higher contribution of crop residues to the PT systems (mainly from the root system) and AC (crop residues of weeds that invade the area in the fallow period) can lead to over time to a higher storage of soil TOC, exceeding the

Table 1. Use History/Record of the systems installed in Red-Yellow Latosol in the State of Espírito Santo, Brazil.

Use system	Symbol	Use History/Record
Native forest	NF	Remnant of native forest located about 500 m away from the other use systems with the same soil class. The state of soil equilibrium was used as reference.
Annual crop (Sorghum)	AC	Area previously cultivated with vegetables for 11 years; in 1994 planting of forage sorghum (*Sorghum bicolor*) for animal feeding. The field was re-planted every year in conventional tillage system using crop-specific cultural practices. The area was left fallow in the second growing season.
Perennial crop (Coffee)	PC	Area previously used as orange orchard for 23 years, where in 2006 conilon coffee farming was implanted (*Coffea canephora*). Crop-specific cultural practices were used including pruning (once a year), leaving the crop residues between the crop rows.
Pasture	PT	Pasture consisting initially of Pernambuco grass, a native species of the region. After 64 years in 1994, *Brachiaria decumbens* was planted and continuously grazed by cattle in semi-intensive regime and without soil fertility management.

Table 2. Total organic carbon contents (OC), light fraction carbon (C-LF), organic carbon percentage in the light fraction in relation to the organic carbon (C-LF/CO) and organic carbon in the heavy fraction (C-HF), in the 0 - 10 cm layer of a Red-Yellow Latosol under different use systems in the State of Espírito Santo, Brazil.

Use system	TOC	C-LF	C-LF/OC	C-HF
	---------- g kg^{-1} ----------		%	g kg^{-1}
NF	14.42 a	3.50 a	24.10 a	10.92 ab
AC	10.57 bc	0.37 b	3.70 b	10.20 b
PC	8.10 c	0.50 b	6.55 b	7.60 c
PT	13.02 b	0.37 b	2.95 b	12.65 a

Averages followed by the same letter in the column do not differ statistically by the Tukey test to the level of 5% of probability. NF= Native forest, AC = annual crop, PC = Perennial crop and PT = pasture.

contents found in the PC system where there is less plant residue input.

Among the cultivation systems, the absence of or the reduction in soil tillage in the PT area resulted in an increase of 60.7 and 23.3%, respectively, in the soil TOC content in this system, in relation to the PC and AC systems. The higher value of OC in AC, similar to the PT system can be explained by the management history of this land with soil tillage and incorporation of residues, lime and fertilizer.

Table 2 shows the TOC contents in the light fraction (C-LF), the relation C-LF/CO and the TOC content of the heavy fraction (C-HF) of SOM in the different land use systems. In the different land use systems, C in the light fraction (C-LF) had highest contents in NF. This indicated that the physical protection of the light fraction of SOM is better in this system. The C-LF contents were greatly reduced in the cultivated areas. In relation to the NF system, where C-LF was 3.5 g kg^{-1}, the contents of this fraction in the systems AC, PC, and PT decreased by 85.71, 89.43 and 89.43%, respectively.

The C in the heavy fraction (C-HF) corresponded, on average, to 90.7% of the soil TOC (Figure 1), increasing the proportion in the following order: NF > PC > AC > PT, with values above 93% in AC, PC and PT. The most labile fraction of SOM (C-LF) represented a small percentage of soil TOC (Table 3). In the evaluated systems, C-LF represented from 2.95 (PT) to 24.1% (NF) of soil TOC. In the forest area, the percentage of C-LF was 3.7 to 8.2 times higher than that in the PC and PT systems.

Carbon storage in the light and heavy fractions of SOM is shown in Table 3. The storage of C-LF varied from 0.44 a 3.85 t ha^{-1} with the highest value in the NF system.

The increase and percentage reductions in carbon contents and storage in samples collected from the different land use systems are shown in Figure 2. The values obtained in the soil of native forest were used as

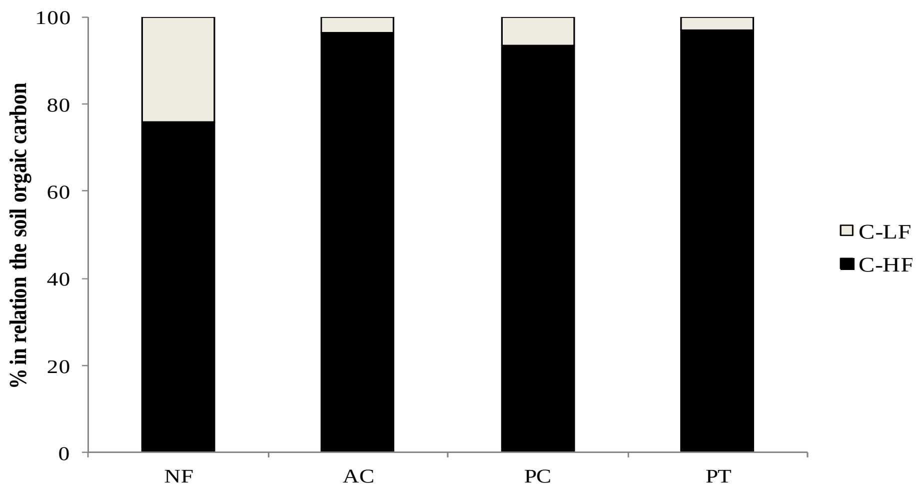

Figure 1. Proportion of carbon contents in the light fraction (C-LF) and carbon in the heavy fraction (C-HF) in relation to the total organic carbon (TOC) of the soil. NF = Native forest, AC = annual crop, PC = perennial crop and PT = pasture. Espírito Santo, Brazil.

Table 3. Bulk density (Bd), storage of organic carbon light fraction and storage of organic carbon heavy fraction in the 0 - 10 cm layer of a Red-Yellow Latosol under different use systems in the State of Espírito Santo, Brazil.

Use system	Bd	Storage C-LF	Storage C-HF
	kg dm^{-3}	------------------- t ha^{-1}	-------------------
NF	1.09 a	3.85 a	11.95ab
AC	1.19 a	0.44b	12.17ab
PC	1.27 a	0.68b	10.18b
PT	1.29 a	0.44b	15.21a

Averages followed by the same letter in the column do not differ statistically by the Tukey test to the level of 5% in probability. NF = Native forest, AC = annual crop, PC = perennial crop and PT = pasture.

reference. Highest variations among the analyzed carbon fractions were detected in the C-HF contents. In the PT system, an average increase in C-HF contents of 15.8% in relation to the forest soil was observed.

DISCUSSION

According to Stevenson (1994), the reduction in the organic matter content of the cultivated soils is due to the reduction in the quantity of residue soil input and to the increase of microbial activity and, consequently, the rate of organic matter decomposition, due to better aeration, increase in soil temperature and the more frequent alternation of wetting and drying cycles of the soil. The increase in C quantities lost by erosion and leaching explains, similarly, the decrease in organic matter in cultivated areas (Ramani et al., 1997) as shown by the contents of OC in the systems with annual and perennial crops (Table 2).

In a study with a Latosol under two types of plant cover [natural vegetation of the Cerrado (Brazilian savannah) and corn cultivation for 30 years]. Passos et al. (2007) concluded that the type of plant cover and soil management influenced the OC contents of the soil. According to Leal et al. (2010), the highest contents of OC in systems without soil tillage can be explained by the factors associated to the protection mechanisms of SOM: recalcitrance, physical protection and chemical molecular interaction.

According to Longo and Espíndola (2000), these reductions in the OC contents in cultivated soils are explained by the fact that organic matter is concentrated in the uppermost soil layers, and is for this reason, more susceptible to microclimatic alterations caused by the use and management systems. These results (Table 2) are in agreement with those of Tiessen et al. (1994) and Mielniczuk et al. (2003). According to these authors, in cultivated areas of the tropics, the high rates of SOM loss result in a reduction of 50% in the original SOM content in relation to the same soil under natural vegetation, in less than 10 years of cultivation, mainly in the systems with

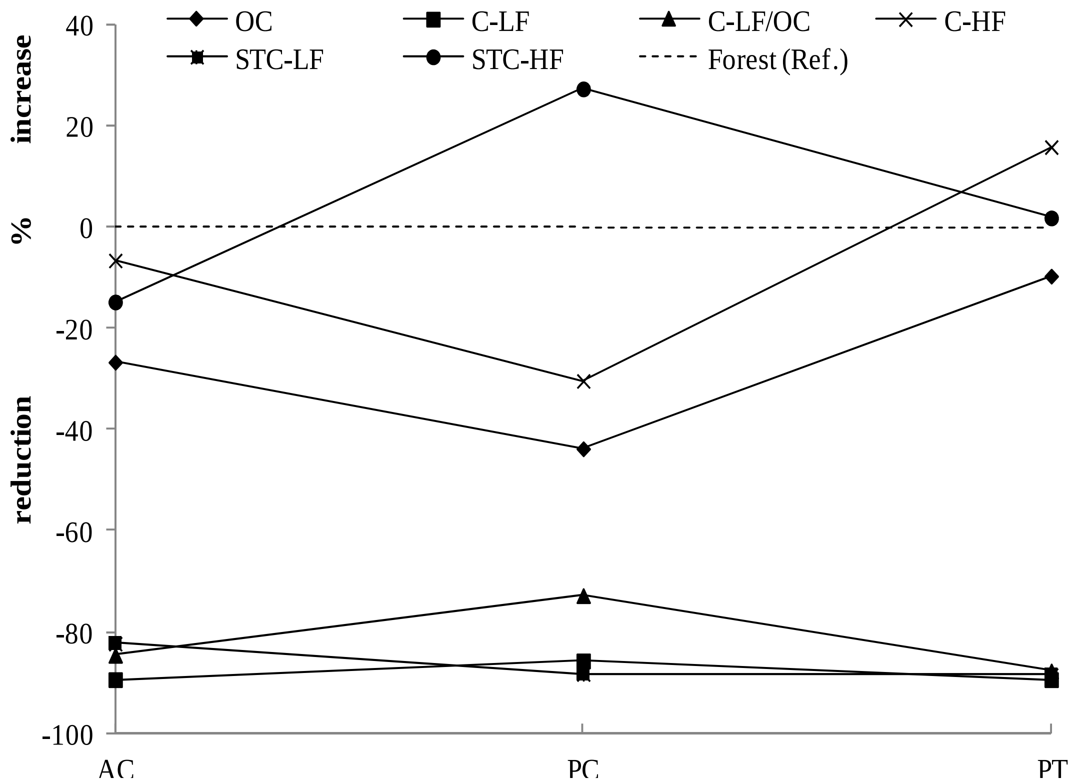

Figure 2. Percentage increase and reduction of the carbon fractions in Red-Yellow Latosol in the systems of annual crop (AC), perennial crop (PC) and pasture (PT) in relation to the native forest (NF-reference). TOC = total organic carbon of the soil; C-LF = carbon in light fraction; C-LF/OC = relation between C-LF and TOC; C-HF = carbon in heavy fraction; STC-LF = storage of carbon in light fraction and; STC-HP = storage of carbon in heavy fraction. Espírito Santo, Brazil.

low input of plant residues.

Doran (1980) reported that soil tillage, as it occurs in some PC systems (hoe-weeding) and periodically in the AC system, causes disturbance inducing stress in the microbial populations and, once the C additions in these systems are lower, there is a higher consume of soil TOC by microorganisms resulting in SOM reduction.

The increase in TOC contents observed in the PT system can be associated to grazing of the grasses, which may have led to the increase in soil TOC contents due to the high deposition of organic matter, the high allocation of photosynthates to the root system, the high root contents of lignin and the higher humification coefficient of the carbon added to the soil (Boddey et al., 2001; Pillon et al., 2001).

Considering the run time of the PC systems (5 years), the absence of soil tillage and the input of residues from cultural practices on the field, higher TOC contents would be expected in this system of soil use. In the AC system, the observed reduction in the TOC contents indicates that: i) the residue contribution and/or conversion to SOM were less efficient than in the forest area (NF); ii) that these systems are more favorable for the decomposition of organic matter in (Silva et al., 2004); iii) or that a longer period is required until the TOC contents in this system come close to those observed in the forest soil. Another factor to be considered is the quality of the residues added to the soil in the evaluated use systems. Silva et al. (2004) reported that plants or younger tissues are richer in proteins, minerals and the water-soluble fraction, whereas the tissues of older plants contain higher proportions of recalcitrant compounds, e.g., cellulose, hemicellulose, lignin, and polyphenols.

These results (Table 3) are in line with Freixo et al. (2002) and Rangel et al. (2007), who reported an average reduction in the C-LF contents of 85 and 89%, respectively, in Latosol under different use systems, in relation to the same soil under native scrubland (study reference).

In non-anthropized systems, such as NF, the source of organic substances is mainly associated to the natural deposition of plant residues that find their way into the soil in the form of leaves, branches and other organic fragments, as well as to organic substances derived from root decomposition (Pohlman and Mccoll, 1988). Rovira and Vallejo (2002) reported that the resistance to acid hydrolysis is higher for the recalcitrant organic polymers (lignins, suberins, resins, and wax). Therefore, the highest C-LF contents found in the NF soil can also be associated to the quality of crop residues applied to the soil, which probably contain higher proportions of carbon that is more recalcitrant from the chemical point of view.

The small contribution of C-LF to the TOC of the soil (C-LF/TOC), mainly in the crop systems, is probably associated to lower residue contribution and to the higher decomposition rate of this fraction in soils that are less structured, more oxygenated, with high temperatures, and plentiful supply of water liming and fertilization (Christensen, 2000). Another explanation for the small participation of the C-LF in the OC of the soil is that the only protection mechanism of this fraction is the recalcitrance of its constituent materials, making the C-LF more available to the microbiota than the HF of SOM (Roscoe and Machado, 2002).

For clay soils of temperate regions, Parfitt et al. (1997) reported a percentage of C-LF varying from 16 to 39% of the soil TOC. However, for clay Latosols of tropical regions under different management systems (forest, scrubland and pasture), Golchin et al. (1995) and Freixo et al. (2002) found that the relation C-LF/OC varied from 1 to 4% of the soil TOC. In a study about the densimetric physical fractionation of SOM in a Latosol under different management systems (forest, eucalyptus, pinus, pasture, and corn), Rangel et al. (2007) reported a variation of 2.3 to 12% of TOC in the relation C-LF/TOC which values similar are to those listed in Table 2 with the exception of the NF system.

The C-HF contents varied from 7.60 to 12.65 g kg^{-1}, with no difference in the contents in the NF from the PT system, as similarly reported by Potes et al. (2010). The storage of C-HF was little influenced by the management systems of the soil, very likely due to the short period of cultivation and the constant tillage of the soil in the AC system, once the following groups of protection mechanisms of SOM act in this fraction: molecular recalcitrance, physical protection and chemical interaction, extending the carbon cycling time in these in relation to the light carbon fraction, where only the molecular recalcitrance mechanism acts (Leal et al., 2010).

The highest storage of C-LF observed in the NF system was probably due to the higher contribution of plant material in relation to the other management systems. According to Six et al. (2002), the C-LF is strongly influenced by the quantity of the dry matter added to the soil, being the storage of C-LF directly proportional to this input.

This behavior differed from that of the C-LF, which decreased in all evaluated systems. For the properties of TOC, C-LF, C-LF/TOC and STC-LF, there was a reduction in relation to the reference system (NF), indicating the susceptibility of organic matter to oxidation in environments with low input of plant residues and management with less emphasis on conservation. Considering the different land use systems, the highest reductions in carbon contents were noted in the C-LF, making this property very useful as an indicator of changes in soil organic matter in different agroecosystems.

Conclusions

The clearing of native forest (NF) and the adoption of different land use systems caused some significant alterations in the contents and storage of the fractions of the evaluated organic matter. In relation to the reference system (NF), there was a reduction in the contents of TOC, C-LF, of the relation C-LF/TOC and in the storage of C-LF in all evaluated use systems. The mean reductions in the evaluated properties were highest in the soil in the area of annual crop (AC) compared to the NF system decreasing 89.4% in the C-LF content. The land use systems showed the following decreasing order of SOM preservation: NF >PT > PC > AC. Carbon in the light fraction (C-LF) was the most sensitive property and reflected the main changes in the OC of the soil and was induced by the different land use systems.

Conflict of Interests

The authors have not declared any conflict of interests.

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