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Carbon in Humic Fractions of Organic Matter in Soil Treated with Organic Composts under Mango Cultivation

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ABSTRACT: Soil organic matter (SOM) plays a key role in maintaining the productivity of tropical soils, providing energy and substrate for the biological activity and modifying the physical and chemical characteristics that ensure the maintenance of soil quality and the sustainability of ecosystems. This study assessed the medium-term effect (six years) of the application of five organic composts, produced by combining different agro-industrial residues, on accumulation and chemical characteristics of soil organic matter. Treatments were applied in a long-term experiment of organic management of mango (OMM) initiated in 2005 with a randomized block design with four replications. Two external areas, one with conventional mango cultivation (CMM) and the other a fragment of regenerating *Caatinga* vegetation (RCF), were used as reference areas. Soil samples were collected in the three management systems from the 0.00-0.05, 0.05-0.10, and 0.10-0.20 m layers, and the total organic carbon content and chemical fractions of organic matter were evaluated by determining the C contents of humin and humic and fulvic acids. Organic compost application significantly increased the contents of total C and C in humic substances in the experimental plots, mainly in the surface layer. However, compost 3 (50 % coconut bagasse, 40 % goat manure, 10 % castor bean residues) significantly increased the level of the non-humic fraction, probably due to the higher contents of recalcitrant material in the initial composition. The highest increases from application of the composts were in the humin, followed by the fulvic fraction. Compost application increased the proportion of higher molecular weight components, indicating higher stability of the organic matter.

Keywords: humin, humic acids, fulvic acids, semi-arid region of Brazil, *Mangifera indica*.

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INTRODUCTION

Soil organic matter (SOM) plays a key role in maintaining the productivity of tropical soils, providing energy and a substrate for biological activity and modifying the physical and chemical characteristics that ensure maintenance of soil quality and the sustainability of ecosystems (Chivenge et al., 2007). The removal of native vegetation for implementation of agricultural practices accelerates decomposition rates due to changes in aeration conditions, temperature, and soil water content, in addition to quantitative and qualitative changes of the applied residues, resulting in a significant reduction in plant residue levels (Wendling et al., 2010; Tivet et al., 2013). Under the conditions of the semi-arid region of Brazil, characterized by high temperatures, low rainfall, little-weathered soil, and low biomass production (Maia et al., 2006), SOM buildup is restricted even under natural conditions. However, in areas of irrigated agriculture, where temperatures are high and irrigation water is present, SOM mineralization is facilitated (Giongo et al., 2011).

Soil management techniques for SOM preservation consist primarily of maintaining crop residues after cultivation, as in no-tillage systems (Assmann et al., 2014), as well as of continuous additions of animal waste, such as swine and cattle manure (Abdala et al., 2015). The addition of residues to the soil in natural or composted form can alter the content and nature of SOM for a relatively long period of time and may result in significant changes in the soil physical, chemical, and biological properties (Damatto Júnior et al., 2006).

The SOM content is the result of a dynamic and sensitive balance among the mechanisms of addition, transformation, and mineralization of the residues entering the system, defined by the local soil and climate characteristics (Horwath, 2015). The understanding of SOM dynamics should not be restricted to total organic carbon (TOC), but include the light fraction of soil organic matter, considered a more sensitive indicator of changes in the quality of soil (Haynes, 2005) and of the humic fractions of organic matter, the most stable components of SOM, representing approximately 40 to 60 % of SOM, and a significant part of total C and N of the soil (Milori et al., 2002; Horwath, 2015). Like the SOM content, the humic fraction/total C ratio has been used as a soil quality indicator, due to the strong interaction of humic substances with mineral material and soil management practices (Canellas and Santos, 2005).

The SOM dynamics in the semi-arid soils of Brazil is not well known, especially in areas with irrigated crops and organic fertilization. However, in an evaluation of soil chemical properties under an organic mango cultivation system with drip irrigation, Silva et al. (2013) found that the application of organic composts increased SOM levels in the semi-arid region of northeastern Brazil.

Thus, the organic fertilization in semi-arid soils should promote changes in SOM, as well as in humic fractions of organic matter. The objective of this study was to evaluate the quantitative changes in SOM after organic compost application in an experimental unit of long-term organic mango cultivation in an irrigated area on a sandy texture *Argissolo Amarelo Eutrófico plintossólico* (Typic Plinthustalf).

MATERIALS AND METHODS

This study was carried out in the Bebedouro experimental field of Embrapa Semiárido in Petrolina, Pernambuco, Brazil (lat 9° 9’ S, long 40° 29’ W, 365.5 m asl). The soil of the experimental area was classified as an *Argissolo Amarelo Eutrófico plintossólico* (Santos et al., 2013), a Typic Plinthustalf (Soil Survey Staff, 2014), with sandy texture. The climate, according to the Köppen classification, is BSwh, with mean annual temperature and rainfall of around 27 °C and 540 mm, respectively.

The experiment was set up in 2005 with mango (*Mangifera indica* L.), cv. Tommy Atkins, in OMM to evaluate the effect of the application of five organic composts with different compositions (Table 1) and a control without compost application. The treatments were arranged in a randomized block design with four replications, for a total of 24 experimental units. The experimental units consisted of four nine-month-old mango plants, and the seedlings were planted in holes (0.50 × 0.50 × 0.50 m) spaced at 6 × 5 m and irrigated by micro sprinklers.

The organic compost treatments were applied before planting, at rates of 40 dm^3 mixed with soil in the planting hole. Complementary fertilizations were subsequently applied, consisting of 40 dm^3 of organic compost per plant in 2008 and 2009. Two areas were used for comparison, one with conventional mango cultivation (CMM) and the other a fragment of regenerating secondary *Caatinga* vegetation (RCF).

The area under conventional management (CMM) was established in 1998 at a plant spacing of 8 × 6 m. Preplanting fertilization consisted of 20 L of cattle manure, 400 g superphosphate, and 500 g lime per planting hole. The area was sprinkler irrigated, and weeds were controlled by hand weeding.

The area containing the fragment of regenerating *Caatinga* vegetation (RCF) had been deforested in 1996 through cutting. After removal of native vegetation, there was no type of cultivation or further human intervention, allowing natural revegetation.

In January 2011, six years after starting the experiment, disturbed soil samples were collected from under the canopy of the mango trees in all plots in the 0.00-0.05, 0.05-0.10, and 0.10-0.20 m layers, blending four single samples into one composite sample per experimental unit. The reference areas (CMM and RCF) were divided into four sub-areas. In each area, 10 single disturbed samples were randomly collected to form a composite sample of each layer. All material was stored in plastic bags and taken to the Soil and Plant Laboratory of *Embrapa Semiárido*. The samples were air dried and clods were broken up and sieved (2 mm) and then stored for chemical analysis.

Total organic carbon (TOC) was analyzed by wet oxidation of the organic material using potassium dichromate in an acidic medium, and external heating followed by titration with ferrous ammonium sulfate (Yeomans and Bremner, 1988). Chemical fractionation of humic substances was based on solubility in alkaline and acid medium, using 0.1 mol L^{-1} NaOH according to a method of Swift (1996) adapted by Mendonça and Matos (2005). Analyses were performed in triplicate; 0.5 g air-dried fine soil (ADFS) and 10 mL of 0.1 mol L^{-1} NaOH were placed in 50.0 mL tubes, which were shaken for 1 h at 120 rpm with a vertical shaker, then centrifuged at 3,000 *g* for 20 min, and the supernatant was collected in a flask. Then, an additional 10 mL of 0.1 mol L^{-1} NaOH was added to the precipitate at the bottom of the tubes. The precipitate remaining in the tube corresponded to the humin fraction (HU), which was dried in a laboratory oven at 45 °C. The alkaline extract (AE) collected in the flask consists of the humic acid (HA) and fulvic acid (FA) fractions; the pH was adjusted to 2.0 with 20 % sulfuric acid solution to separate these

Table 1. Composition of residues in the mounds for preparation of the composts used in the experimental area

Component	Composition				
	1	2	3	4	5
	%				
Sugarcane trash	50	67			
Coconut bagasse			50	67	
Goat manure	40	33	40	33	10
Castor bean residue	10		10		
Urucu bark					50
Elephant grass					40

two fractions. Organic C was determined in each of the organic fractions by the method described above for TOC. The fraction of humic substances (HS) was obtained by the sum of C of the three fractions, and the fraction of non-humic substances (NHS) was calculated as the difference between TOC and humified C (HS).

Compost samples were also subjected to humic substance extraction by the alkaline extraction procedure described by Swift (1996), without determining the humin component. From the data, we estimated the fraction of humic substances (HS) by the sum of the different fractions; the fraction of non-humic substances (NHS) was estimated as the difference between TOC and HS; the alkaline extract/humin ratio (AE/HU) and the humic acid/fulvic acid ratio (HA/FA) were also calculated.

The variables evaluated in the experimental area were subjected to analysis of variance and the means compared by the Tukey test at 5 % probability (Ferreira, 2000). The data collected in the reference areas were compared with treatments of the OMM area by means of confidence intervals for the mean.

RESULTS AND DISCUSSION

The composts were collected and stored once their original materials had become indistinguishable. The concentrations of C, N, P, and K were highest in compost 3, while N and C concentrations in composts 1 and 5 were similar and lower than in compost 3 (Table 2). The concentrations of the elements assessed were highest in these three composts, due to the greater diversity of residue constituents. In general, the C/N ratio varied from 13.23 to 18.23. Variation among the levels of humified substances determined by alkaline extraction (1.0 mol L^{-1} NaOH) was not high. However, in compost 1, the proportion of fulvic acid in the alkaline extract fraction was predominant. Proportionally, compost 2 had the highest C content extracted in alkaline medium (10.7 %), and consequently the highest proportion of mass converted into HA and FA. Although humin production could not be determined by the method, the rate of humic substances extracted in alkaline medium was lowest in compost 3. However, this is most likely a result of a lower conversion of the coconut residues, which are rich in fibers and recalcitrant substances.

TOC contents were highest in the 0.00-0.05 m layer in all areas studied (Table 2). In the experimental area, organic management with the addition of different composts induced significantly different cumulative TOC levels. The plots treated with composts 1 and 3 contained the highest C levels, differing from the control and compost 4 in the 0.00-0.05 m layer (Table 2). In the 0.05-0.10 m layer, compost 3 also resulted in a higher TOC content, differing from the control. In the 0.10-0.20 m layer, however, no significant difference among treatments was observed (Table 2). Compared to the reference areas, the TOC levels were similar to the control treatment in all layers, confirming the effect of compost application on C accumulation in the soil.

The higher TOC found in treatments with composts 1 and 3 in the 0.00-0.05 m layer and compost 3 in the 0.05-0.10 m and deeper layers are related to the characteristics of the

Table 2. Chemical characterization of the composts used in an area under mango in organic management

Compost	C	N	P	K	Ca	Mg	S	Na	HA	FA	HA/FA	C/N
	g kg^{-1}											
1	272.4	15.8	3.79	0.12	21.72	1.88	1.05	0.10	6.24	8.40	0.74	17.24
2	132.1	9.57	1.63	0.72	9.97	1.42	1.31	0.10	7.84	6.24	1.25	13.80
3	349.8	19.2	4.23	1.32	21.11	1.84	2.11	0.12	6.96	6.24	1.11	18.23
4	196.9	14.7	2.44	0.72	13.88	1.80	1.25	0.11	7.45	5.52	1.34	13.35
5	270.4	16.7	1.80	0.12	10.87	2.40	1.55	0.06	7.32	5.67	1.29	16.20

respective composts, which have a higher C/N ratio than the others. The C/N ratio of organic waste has a direct influence on the performance of microorganisms, determining the ratio of decomposition of the materials used in this process (Kiehl, 1985). The dynamic nature of this ratio is explained by the fact that C is the energy source and N is the basic source for reproduction and cell growth (Suszec, 2005).

Total OC accumulated in the soil resulting from the application of different organic composts is well documented in the literature. Fernandes et al. (2005) and Santos et al. (2009), for example, detected that the addition of sewage sludge resulted in TOC accumulation in the soil. By application of compost derived from residues of olive oil extraction, Casacchia et al. (2012) obtained a 72 % increase in TOC levels. Similarly, Clemente et al (2012) obtained higher levels of SOM and of nutrients and increased microbial activity from the application of a similar compost. In studies in commercial fields with irrigated mango cultivation in the semi-arid region of Brazil, Silva et al. (2013) applied organic fertilizer with compost and obtained results similar to this study, with an increase in TOC content, depending on the initial composition of the compost. In a study by Damatto Júnior et al. (2006), fertilization with organic compost of sawdust and manure improved SOM, pH, P, Ca, sum of bases, CEC, and base saturation in the 0.00-0.20 m layer of soil under banana. The increase in TOC reported by the authors was attributed to the C derived from the aforementioned materials used in management of the areas.

The C contents of the non-humified SOM fraction (NHS) increased significantly ($p<0.05$) in all treatments in the surface layer, compared to the control (Table 3). However, only treatments with application of composts 1, 3, and 4 resulted in higher levels of humic substances (HS) than in the control treatment, and these differences were only observed in the surface layer. The reference areas had low C contents in the different fractions, which were similar to the control treatment.

Although humic substances (HS) are more stable under changes resulting from management operations, the NHS, also called the light fraction, was accumulated, probably due to the recalcitrant compounds in the source material of the organic composts. Similar results of HS accumulation were reported by Adani et al. (2007) for soil treated with organic compost for four years. The soil conservation management systems also resulted in accumulation of humic compounds, as reported in a study in a crop/forest/pasture system (Martins et al., 2009). This increase improved chemical and physical soil properties, resulting in greater resistance to OC loss. Humic substances represent the compartment with the most stable SOM fraction. These substances are the result of chemical and biological transformations of plant residues and synthetic activity of soil microflora, representing the highest and most stable percentage of soil TOC. Humic substances accounted for approximately 70 to 80 % of SOM (Moreira and Siqueira, 2006) and have a high degree of polymerization, high surface reactivity, and high molecular weight, acting as a nutrient reservoir and contributing to chemical stabilization of microaggregates (Silva and Mendonça, 2007).

The increase in the HS-C observed in the compost treatments occurred only in the fulvic acid (FA) and humin (HU) fractions, with no significant differences in the humic acid (HA) fraction (Table 4). In the treatment with compost 1, HU increased by 70 % in the 0.00-0.05 m layer. In the other layers, no differences were observed among treatments, except for FA in treatment 1, resulting in a higher FA content of the compost at the end of the preparation process. At the beginning of the maturation process, the FA fraction was high, since it was synthesized first. Incomplete maturation of the organic material can result in disproportionate amounts of low molecular weight fractions, i.e., the FA fraction (Tomati et al., 2002). Similar results of increased FA levels in deeper layers were reported by Canellas et al. (2000). The authors reported on the FA movement following the water movement.

The CMM and RCF areas have lower C contents in HU in the 0.00-0.05 m layer than treatments with different composts. This behavior is widely observed in tropical soils, e.g., in soils of tropical Africa (Dabin, 1981) and of the Amazon forest (Cunha et al., 2007).

Table 3. Total Organic Carbon (TOC), carbon in humic substances (HS) and non-humic substances (NHS) of soil fertilized with organic composts and of reference areas

Treatment	0.00-0.05 m	0.05-0.10 m	0.10-0.20 m
		TOC (g kg^{-1})	
Compost 1	25.89 (±4.14) a	7.41 (±0.40) bc	4.21 (±0.40) a
Compost 2	20.31 (±5.50) abc	9.49 (±0.48) ab	5.34 (±0.48) a
Compost 3	28.97 (±4.52) a	10.09 (±0.19) a	5.29 (±0.29) a
Compost 4	19.65 (±2.96) bc	8.84 (±0.70) ab	4.71 (±0.07) a
Compost 5	19.79 (±4.96) ab	8.72 (±0.96) b	5.93 (±1.96) a
Control	12.25 (±2.07) c	7.38 (±0.48) c	5.92 (±0.84) a
CV (%)	15.44	12.88	16.24
Conventional	9.90 (±3.36)	8.54 (±1.27)	7.58 (±1.27)
Caatinga	10.67 (±2.13)	6.71 (±0.60)	4.41 (±0.60)
		C - Humic substances (g kg^{-1})	
Compost 1	19.06 (±4.78) a	7.68(±2.66) a	5.17 (±2.41) a
Compost 2	11.65 (±4.19) bc	7.53 (±2.24) a	4.41 (±2.10) a
Compost 3	12.47 (±5.28) b	8.38 (±3.94) a	5.58 (±3.09) a
Compost 4	13.89 (±3.26) b	7.62 (±2.73) a	6.31 (±4.11) a
Compost 5	10.72 (±2.91) c	8.50 (±3.39) a	5.73 (±3.49) a
Control	10.27 (±3.30) c	7.32 (±3.36) a	5.17 (±3.89) a
CV (%)	13.14	11.47	10.85
Conventional	8.81 (±0.99)	5.07 (±0.98)	3.80 (±0.51)
Caatinga	9.89 (±2.25)	6.90 (±1.51)	5.84 (±1.35)
		C – Non-humic substances (g kg^{-1})	
Compost 1	6.83 (±2.45) b	1.27 (±0.72) a	0.96 (±0.22) a
Compost 2	8.65 (±1.65) b	1.96 (±1.10) a	0.93 (±0.61) a
Compost 3	16.51 (±1.9) a	0.53 (±0.60) a	0.29 (±0.22) a
Compost 4	4.75 (±1.15) b	0.72 (±1.00) a	1.60 (±0.45) a
Compost 5	9.07 (±2.95) b	0.23 (±0.55) b	0.20 (±1.11) a
Control	1.87 (±1.10) c	1.06 (±1.30) a	0.74 (±0.82) a
CV (%)	16.82	14.34	18.48
Conventional	2.23 (±0.75)	3.47 (±0.70)	3.78 (±0.23)
Caatinga	1.90 (±0.90)	0.73 (±0.55)	0.79 (±0.05)

Means followed by the same letter in the columns do not differ at 5 % by the Tukey test. Values in brackets refer to the confidence interval (n = 4) (α = 0.5). Organic mango management with compost 1, compost 2, compost 3, compost 4, compost 5, and control; Conventional mango management; and fragment of regenerating *Caatinga* vegetation.

Moreover, Fontana et al. (2011) and Guimarães et al. (2013) evaluated compartments of SOM in areas with different vegetation cover and noted a predominance of HU followed by FA. High concentrations of C in HU in the surface layer may be related to intense microbial activity and, consequently, to a higher SOM decomposition rate (Guimarães et al., 2013).

The HA/FA ratio can be considered an index of humification of organic matter in the soil. The lower HA/FA ratio, the lower the humification rates of organic matter, which may be driven by edaphic processes, soil management and/or recent input of organic matter (Stevenson, 1994). Fulvic acids are the most reactive fractions, but with lower chemical stability. This indicates an unfavorable characteristic, which can facilitate cation leaching and illuviation of humified clays in the form of organic complexes. Caetano et al. (2013) consider the FA and light organic matter more sensitive to changes caused by agricultural soil management than TOC. In tropical soils, the intense mineralization of organic matter and restrictions to soil biological activity reduce the HA/FA ratio (Benites et al., 2003).

Table 4. Carbon in soil humic fractions and the relationship between fractions of soil fertilized with organic composts and of reference areas

Treatment	HU	HA	FA	HA/FA	AE/HU
	g kg^{-1}				
			0.00-0.05 m		
Compost 1	11.08 (±6.03) a	2.49 (±0.58) a	5.49 (±0.77) a	0.45 (±0.12) b	0.72 (±0.16) a
Compost 2	6.02 (±1.15) ab	2.56 (±0.40) a	3.06 (±0.40) b	0.84 (±0.06) ab	0.93 (±0.18) a
Compost 3	7.83 (±1.63) ab	2.21 (±0.33) a	2.39 (±0.33) bc	0.94 (±0.38) ab	0.59 (±0.00) a
Compost 4	9.30 (±1.60) ab	2.28 (±0.57) a	2.25 (±0.34) bc	1.01 (±0.23) a	0.49 (±0.23) a
Compost 5	6.05 (±1.84) ab	2.32 (±0.30) a	2.20 (±0.53) c	1.05 (±0.25) a	0.75 (±0.16) a
Control	6.51 (±0.78) b	1.60 (±0.58) a	1.59 (±0.34) c	1.01 (±0.23) a	0.49 (±0.23) a
CV (%)	26.2	21.44	16.01	21.44	26.2
Conventional	5.92 (±0.18)	0.96 (±0.33)	1.67 (±0.34)	0.56 (±0.17)	0.44 (±0.34)
Caatinga	5.23 (±0.43)	2.70 (±0.68)	1.97 (±0.36)	1.37 (±0.28)	1.42 (±0.56)
			0.05-0.10 m		
Compost 1	3.65 (±0.29) a	1.78 (±0.40) a	3.24 (±0.26) a	0.55 (±0.13) a	1.38 (±0.29) a
Compost 2	3.76 (±1.12) a	1.59 (±0.00) a	2.16 (±0.57) b	0.74 (±0.22) a	0.99 (±0.62) ab
Compost 3	5.30 (±0.77) a	1.49 (±0.40) a	1.60 (±0.00) b	0.93 (±0.28) a	0.58 (±0.37) b
Compost 4	3.78 (±0.44) a	1.67 (±0.35) a	2.17 (±0.93) b	0.77 (±0.31) a	1.01 (±0.41) ab
Compost 5	4.31(±0.73) a	1.25 (±0.35) a	2.53 (±0.00) b	0.49 (±0.24) a	0.88 (±0.43) ab
Control	3.30 (±0.31) a	1.03 (±0.58) a	2.16 (±0.93) b	0.48 (±018) a	0.97 (±0.31) ab
CV (%)	23.25	27.56	24.43	21.8	20.6
Conventional	3.27 (±0.42)	0.72 (±0.0)	1.26 (±0.67)	0.70 (±0.33)	0.61 (±0.42)
Caatinga	3.16 (±0.89)	1.97(±0.68)	1.08 (±0.40)	1.99(±0.80)	0.97 (±0.89)
			0.10-0.20 m		
Compost 1	1.57 (±0.46) a	1.63 (±0.56) a	1.98 (±0.37) a	0.82 (±0.37) b	2.30 (±0.67) a
Compost 2	2.27 (±0.80) a	1.23 (±0.28) a	0.90 (±0.40) b	1.37 (±0.10) a	0.94 (±0.74) a
Compost 3	2.86 (±0.36) a	1.06 (±0.37) a	1.66 (±0.41) ab	0.64 (±0.01) c	0.95 (±0.56) a
Compost 4	2.65 (±0.18) a	2.16 (±0.43) a	1.48 (±0.35) ab	1.46 (±0.24) a	1.37 (±0.18) a
Compost 5	2.30 (±0.07) a	1.81 (±0.35) a	1.63 (±0.00) ab	1.11 (±0.03) ab	1.50 (±0.21) a
Control	2.23 (±0.63) a	1.86 (±0.35) a	1.68 (±0.00) ab	1.11 (±0.08) ab	1.59 (±0.56) a
CV (%)	21.34	35.71	23.42	35.71	31.34
Conventional	2.36 (±0.22)	0.54 (±0.35)	0.99 (±0.35)	0.62 (±0.46)	0.61 (±0.22)
Caatinga	1.93 (±0.64)	1.61 (±0.35)	0.90 (±0.35)	1.99 (±0.64)	1.30 (±0.64)

Means followed by the same letter in the columns do not differ at 5 % by the Tukey test. Values in brackets refer to the confidence interval (n = 4) (α = 0.5). Organic mango management with compost 1, compost 2, compost 3, compost 4, compost 5, and control; Conventional mango management; and fragment of regenerating *Caatinga* vegetation.

In this study, organic management with application of different composts in a six-year period resulted in a HA/FA ratio lower than 1, both in the conventional management system and in treatments with composts, in all layers, thus indicating the predominance of FA over HA and low polymerization of humic substances as a result of low humification (Table 4). Although the organic residues studied by Dias et al. (2007) were from another origin, the results in *Latossolo* successively treated with sewage sludge were similar. Nevertheless, the HA/FA ratio was greater than 1 in all layers under natural conditions, as also observed by Cunha et al. (2007) in Amazon forest soils. Although the climate characteristics of the environment are different, Fontana et al. (2011) also found HA/FA ratios ranging from 0.6 to 0.9 in areas with different vegetation cover in the Atlantic forest region, with lowest values in the most disturbed areas.

The impact of conventional management on the physical properties and the content and quality of humic substances in an Oxisol, originally under *Cerrado* (Brazilian tropical savanna) and then under a soybean-maize rotation with different cultivation and fallow periods after slash-and-burn clearing were studied by Cunha et al. (2001). They found that fulvic acids and humin increased and humic acids decreased over the course of time.

The HA/FA ratio was also associated with the difference in potential mobility of C fractions in the soil profile, indicating greater illuviation potential of SOM fulvic fractions (Benites et al., 2003). Moreover, sandy soil may have a higher HA/FA ratio, due to solubility and selective loss of organic compounds with higher solubility (Caetano et al., 2013). These FA characteristics may therefore be responsible for FA accumulation in the 0.05-0.10 m layer through addition of compost 1 under the conditions of the sandy texture soil under study.

The AE/HU ratio ranged from 0.49 to 0.93 in the 0.05-0.10 m layer (Table 4), indicating predominance of HU in the different treatments with organic composts, with no significant difference among them. These results indicate that, in general, the application of organic compost in the soil favored a higher proportion of higher molecular weight components at this depth and the accumulation of organic matter of higher stability (HU). In the 0.05-0.10 m layer, the AE/HU values range from 0.62 to 1.37, with a significant difference among treatments, and the highest values were obtained from compost 1, indicating predominance of humic and fulvic substances, and compost 3 had the lowest value, indicating predominance of HU. In the 0.10-0.20 m layer there was no statistical difference among treatments. The likely route of formation of this fraction is by inheritance, which describes a direct evolution of the lignified insoluble compounds present in little-transformed organic matter and which essentially constitutes inherited humin or residual humin (Duchaufour, 1977).

Long-term studies of the effect of organic manure on SOM properties are scarce, but Dias et al. (2007) reported an increase in TOC content as a result of sewage sludge application on maize for eight years in São Paulo. Similar results were reported by Leite et al. (2003) as a result of organic fertilization of maize for 17 years in the region of Zona da Mata, Minas Gerais, Brazil, although the authors also found lower TOC than in the reference area with native forest. Our study, however, was performed under the soil and weather conditions of the semi-arid region of the lower mid São Francisco Valley region in an area of perennial crops and irrigation, and the results showed that compost application in all treatments significantly increased the TOC content in the topsoil compared to the control, with levels almost twice as high as in the reference areas. This is related to the influence of the regional climate and soil conditions on the deposition of plant residues concentrated at the end of the rainy season and the high biological activity in this period, due to high temperatures. Consequently, semi-arid soils are characterized by low contents of organic matter, which is rapidly decomposed through the introduction of agricultural activities and intensified by the uninterrupted availability of water in irrigated areas (Giongo et al., 2011). Therefore, activities to ensure incorporation of organic residues into the soil under these conditions are important for maintaining soil quality.

CONCLUSIONS

The addition of the different composts increased the content of organic carbon in the surface layers (0-0.05 and 0.05-0.10 m) of the treated plots when compared to the control treatment, and also compared both to the natural vegetation and to the conventional area. The treatments increased significantly the content of humic substances when compared to the control and references areas. Furthermore the strongest effect was observed for the non-humic substances.

The content of recalcitrant materials in the residues governed the humification rate of the composts, resulting in differences in the content of humin and humic and fulvic acids of the soil, and also in the degree of humification of SOM.

The compost using the greater proportion of coconut bagasse resulted in the higher content of SOM but it did not affect the content of the humic fractions. In fact, the compost using sugarcane trash and higher amounts of manure and castor bean residue enhanced the content of fulvic acid in the subsurface layer. Therefore, the use of compost in the soil management in the semiarid conditions of the São Francisco Valley should consider the effect of the different residues in the final quality of the compost, and consequently over the desired response of the soil attributes.

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REFERENCES

Abdala DB, Silva IR, Vergütz L, Sparks DL. Long-term manure application effects on phosphorus speciation, kinetics and distribution in highly weathered agricultural soils. Chemosphere. 2015;119:504-14. doi:10.1016/j.chemosphere.2014.07.029

Adani F, Genevini P, Ricca G, Tambone F, Montoneri E. Modification of soil humic matter after 4 years of compost application. Waste Manage. 2007;27:319-24. doi:10.1016/j.wasman.2010.04.030

Assmann JM, Anghinoni I, Martins AP, Costa SEVFA, Cecagno D, Carlos FS, Carvalho PCF. Soil carbon and nitrogen stocks and fractions in a long-term integrated crop-livestock system under no-tillage in southern Brazil. Agric Ecosyst Environ. 2014;190:52-9. doi:10.1016/j.agee.2013.12.003

Benites VM, Madari B, Machado PLOA. Extração e fracionamento quantitativo de substâncias húmicas do solo: um procedimento simplificado de baixo custo. Rio de Janeiro: Embrapa Solos; 2003. (Comunicado técnico, 16).

Caetano JO, Benites VM, Silva GP, Silva IR, Assis RL, Cargnelutti Filho A. Dinâmica da matéria orgânica de um Neossolo Quartzarênico de Cerrado convertido para cultivo em sucessão de soja e milheto. Rev Bras Cienc Solo. 2013;37:1245-55. doi:10.1590/S0100-06832013000500014

Canellas LP, Santos GA, editores. Humosfera: tratado preliminar sobre a química das substâncias húmicas. Campos dos Goytacazes: Universidade Estadual do Norte Fluminense; 2005.

Canellas LP, Berner PG, Silva SG, Silva MB, Santos GA. Frações da matéria orgânica em seis solos de uma toposseqüência no estado do Rio de Janeiro. Pesq Agropec Bras. 2000;35:133-43. doi:10.1590/S0100-204X2000000100016

Casacchia T, Sofo A, Zelasco S, Perri E, Toscano P. *In situ* olive mill residual co-composting for soil organic fertility restoration and by-product sustainable reuse. Ital J Agron. 2012;7:167-70. doi:10.4081/ija.2012.e23

Chivenge PP, Murwira HK, Giller KE, Mapfumo P, Six J. Long-term impact of reduced tillage and residue management on soil carbon stabilization: implications for conservation agriculture on contrasting soils. Soil Till Res. 2007;94:328-37. doi:10.1016/j.still.2006.08.006

Clemente R, Walkerb DJ, Pardoa T, Fernández DM, Bernal MP. The use of a halophytic plant species and organic amendments for the remediation of a trace elements-contaminated soil under semi-arid conditions. J Hazard Mater. 2012;223-224:63-71. doi:10.1016/j.jhazmat.2012.04.048

Cunha TJF, Madari BE, Benites VM, Canellas LP, Novotny EH, Moutta RO, Trompowsky PM, Santos GA. Fracionamento químico da matéria orgânica e características de ácidos húmicos de solos com horizonte a antrópico da Amazônia (Terra Preta). Acta Amaz. 2007;37:91-8. doi:10.1590/S0044-59672007000100010

Cunha TJF, Macedo JR, Ribeiro LP, Palmieri F, Freitas PL, Aguiar AC. Impacto do manejo convencional sobre propriedades físicas e substâncias húmicas de solos sob cerrado. Cienc Rural. 2001;31:27-36. doi:10.1590/S0103-84782001000100005

Dabin B. Análise de compostos húmicos dos solos. [S.l.: s.n.]; 1981.

Damatto Júnior ER, Villas Bôas RL, Leonel S, Fernandes DM. Alterações em propriedades de solo adubado com doses de composto orgânico sob cultivo de bananeira. Rev Bras Frutic. 2006;28:546-9. doi:10.1590/S0100-29452006000300048

Dias BO, Silva CA, Soares EMB, Bettiol W. Estoque de carbono e quantificação de substâncias húmicas em Latossolo submetido a aplicação contínua de lodo de esgoto. Rev Bras Cienc Solo. 2007;31:701-11. doi:10.1590/S0100-06832007000400011

Duchaufour P. Pedologie: pédogenése et classification. Paris: Orstom; 1977.

Fernandes SAP, Bettiol W, Cerri CC, Camargo P. Sewage sludge effects on gas fluxes at the soil-atmosphere interface, on soil 13C and on total soil carbon and nitrogen. Geoderma. 2005;125:49-57. doi:10.1016/j.geoderma.2004.06.008

Ferreira DF. Manual do sistema SISVAR para análises estatísticas. Lavras: Universidade Federal Lavras; 2000.

Fontana A, Silva CF, Pereira MG, Loss A, Brito RJ, Benites VM. Avaliação dos compartimentos da matéria orgânica em área de Mata Atlântica. Acta Sci Agron. 2011;33:545-50. doi:10.4025/actasciagron.v33i3.5169

Giongo V, Galvão SRS, Mendes AMS, Gava CAT, Cunha TJF. Soil organic carbon in the Brazilian semi-arids tropics. Dyn Soil Dyn Plant. 2011;5:12-20.

Guimarães DV, Gonzaga MIS, Silva TO, Silva TL, Dias NS, Matias MIS. Soil organic matter pools and carbon fractions in soil under different land uses. Soil Till Res. 2013;126:177-82. doi:10.1590/01000683rbcs20150048

Haynes RJ. Labile organic matter fractions as central components of the quality of agricultural soils. Adv Agron. 2005;85:221-68. doi:10.1016/S0065-2113(04)85005-3

Horwath W. Carbon cycling: the dynamics and formation of organic matter. In: Paul EA, editor. Soil microbiology, ecology and biochemistry. 4th ed. New York: Academic Press; 2015. p.339-82.

Leite LFC, Mendonça ES, Neves JCL, Machado PLOA, Galvão JCC. Estoques totais de carbono orgânico e seus compartimentos em Argissolo sob floresta e sob milho cultivado com adubação mineral e orgânica. Rev Bras Cienc Solo. 2003;27:821-32. doi:10.1590/S0100-06832003000500006

Maia SMF, Xavier FAS, Oliveira TS, Mendonça ES, Araújo Filho JA. Impactos de sistemas agroflorestais e convencional sobre a qualidade do solo no semi-árido cearense. Rev Árvore. 2006;30:837-48. doi:10.1590/S0100-67622006000500018

Martins EL, Coringa JES, Weber OLS. Carbono orgânico nas frações granulométricas e substâncias húmicas de um Latossolo Vermelho-Amarelo distrófico - LVAd sob diferentes agrossistemas. Acta Amaz. 2009;39:655-60. doi:10.1590/S0044-59672009000300021

Mendonça ES, Matos ES. Matéria orgânica do solo: métodos de análise. Viçosa, MG: Universidade Federal de Viçosa; 2005.

Milori DMBP, Martin-Neto L, Bayer C, Mielniczuk J, Bagnato VS. Humification degree of soil humic acids determined by fluorescence spectroscopy. Soil Sci. 2002;167:739-49. doi:10.1097/00010694-200211000-00004

Moreira FMS, Siqueira JO. Microbiologia e bioquímica do solo. 2ª. ed. Lavras: Universidade Federal de Lavras; 2006.

Kiehl EJ. Fertilizantes orgânicos. São Paulo: Agronômica Ceres; 1985.

Santos JA, Santos VB, Araújo ASF. Alterações na atividade microbiana e na matéria orgânica do solo após aplicação de lodo de esgoto. Biosci J. 2009;25:17-23.

Santos HG, Jacomine PKT, Anjos LHC, Oliveira VA, Lumbreras JF, Coelho MR, Almeida JA, Cunha TJF, Oliveira JB. Sistema brasileiro de classificação de solos. 3ª ed. Brasília, DF: Embrapa; 2013.

Silva DJ, Mouco MAC, Gava CAT, Giongo V, Pinto JM. Composto orgânico em mangueiras (*Mangifera indica* L.) cultivadas no semiárido do nordeste brasileiro. Rev Bras Frutic. 2013;6:875-82. doi:10.1590/S0100-29452013000300026

Silva IR, Mendonça ES. Matéria orgânica do solo. In: Novais RF, Alvarez V VH, Barros NF, Fontes RLF, Cantarutti RB, Neves JCL, editores. Fertilidade do solo. Viçosa, MG: Sociedade Brasileira de Ciência do Solo; 2007. p.275-374.

Soil Survey Staff. Keys to soil taxonomy. 12th.ed. Washington, DC: United States Department of Agriculture, Natural Resources Conservation Service; 2014.

Suszec M. Efeitos da inoculação na compostagem e vermicompostagem de resíduos sólidos verdes urbanos [dissertação]. Cascavel: Universidade Estadual do Oeste do Paraná; 2005.

Stevenson FJ. Humus chemistry. New York: John Wiley; 1994.

Swift RS. Organic matter characterization. In: Sparks OL, editor. Methods of soil analysis: chemical methods. Madison: Soil Science Society of America; 1996. p.1011-20.

Tivet F, Sá JCM, Lal R, Borszowskei PR, Briedis C, Santos, JB, Sá MFM, Hartman DC, Eurich G, Farias A, Bouzinac S, Séguy L. Soil organic carbon fraction losses upon continuous plow-based tillage and its restoration by diverse biomass-C inputs under no-till in sub-tropical and tropical regions of Brazil. Geoderma. 2013;209-210: 214-25. doi:10.1016/j.geoderma.2013.06.008I

Tomati U, Belardinelli M, Andreu M, Galli E, Capitani D, Proietti N, De Simone C. Evaluation of commercial compost quality. Waste Manage Res. 2002;20:389-97. doi: 10.1177/0734242X0202000502

Yeomans JC, Bremner JM. A rapid and precise method for routine determination of organic carbon in soil. Commun Soil Sci Plant Anal. 1988;19:1467-76. doi:10.1080/00103628809368027

Wendling B, Jucksch I, Mendonça ES, Alvarenga RC. Organic-matter pools of soil under pines and annual cultures. Commun Soil Sci Plant Anal. 2010;41:1707-22. doi:10.1080/00103624.2010.489135