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ORGANIC MATTER AND CARBON MANAGEMENT INDEX OF SOIL TREATED WITH COMPOSTED AND NON-COMPOSTED LAYERED RESIDUES[1]

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ABSTRACT - The use of organic residues and compost is a common practice to improve soil quality and content of organic matter. In this study, the labile and stable fractions of soil organic matter were evaluated after application of layers of fresh (non-composted) or composted organic residues in a 6-year-old citrus orchard. The experiment was set up as a randomized block design, with 6 treatments: control without NPK, control with NPK, non-composted organic residue (NCOR, with and without NPK), and composted organic residue (humus, with and without NPK), with three replicates. The treatments were applied under the plant canopy. Soil samples were collected from the 0-0.05, 0.05-0.10, and 0.10-0.15 m layers. There were increases of 10.3, 22.4, 16.3, and 37.1 % in the organic carbon contents of the surface soil for the treatments using NCOR without NPK, NCOR with NPK, humus with NPK, and humus without NPK, respectively. The organic carbon contents of the labile fraction varied from 1.0 to 12.8 g kg^{-1}, representing between 8 and 62 % of the total carbon. The carbon concentrations in the stable fraction varied from 3.1 to 9.7 g kg^{-1}, representing between 38 and 92 % of the total carbon, and this was the dominant fraction for most of the treatments.

Keywords: Physical fractionation. Soil quality. Alternate layering of residues.

MATÉRIA ORGÂNICA E ÍNDICE DE MANEJO DE CARBONO DE SOLO TRATADO COM RESÍDUO COMPOSTADO E EM COMPOSTAGEM LAMINAR

RESUMO – O uso de resíduos orgânicos e composto é uma prática comum para aumentar os teores de matéria orgânica e a qualidade do solo. Neste estudo, foram aplicados resíduos orgânicos compostados (húmus) e frescos, em compostagem laminar, em um pomar de citros com 6 anos com o objetivo de avaliar as frações lábeis e estáveis da matéria orgânica. O experimento foi disposto em blocos casualizados, com seis tratamentos (Controle–NPK, controle + NPK, resíduo fresco com e sem NPK, resíduo compostado, com e sem NPK), com três repetições, aplicados na projeção da copa. As amostras de solo foram coletadas nas camadas de 0-0.05, 0.05-0.10 e 0.10-0.15 m. Houve aumento de 10,3; 22,4; 16,3 e 37,1 % no teor de carbono nos tratamentos com resíduo não compostado, com e sem NPK, e com resíduo compostado, com e sem NPK, respectivamente. O teor de carbono na fração lábil variou de 1 a 12,8 g kg^{-1}, representando de 8 a 62 % do carbono total, e de 3,1 a 9,7 g kg^{-1}, representando 38 a 92 % do carbono total, sendo esta a fração dominante na maioria dos tratamentos.

Palavras-chave: Fracionamento físico. Qualidade do solo. Compostagem laminar.

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INTRODUCTION

Productive agriculture and pasture on weathered soils are strongly dependent on the soil organic matter (SOM) content. In addition to the naturally low amount of SOM in such soils, previous studies have shown that SOM can be further depleted as a result of land use change and conventional management with constant soil cultivation and removal of crop residues (GUIMARÃES et al., 2013). The shift from a natural ecosystem to an agroecosystem can lead to significant changes in carbon inputs and turnover rates. Therefore, it is important to maintain the SOM by continuous addition of crop residues to the soil in the form of mulches, using compost, manures, and domestic and municipal wastes.

It is well known that application of crop residues and animal waste to soil usually increases the soil carbon pool, microbial activity, and soil quality (JAOUDÉ; LAGOMARSINO; DE ANGELIS, 2011). Plant biomass, the primary source of bulk soil organic matter, consists of a heterogeneous mixture of molecules with a wide range of turnover times. Animal manure has long been used as an organic source of plant nutrients and organic matter to improve the physical and fertility conditions of agricultural lands. However, management using organic materials requires knowledge about their quality and outcomes in soil. This is because after microbial attack, new compounds with different decomposition rates and lifetimes are formed in different fractions of the soil, which can cause varied impacts on soil quality.

The labile fraction of SOM (uncomplexed SOM), which decomposes rapidly and has a short lifetime in the soil, is important in nutrient cycling and availability (TIAN et al., 2013). In contrast, the stable fraction of SOM (complexed SOM) is slow to degrade and has a much longer lifetime, so it contributes to the structure, water retention, and CEC of the soil. These two fractions are generally differentiated using physical fractionation methods (CAMBARDELLA; ELLIOT, 1992).

Knowledge of the physical fractions of SOM is important for the development of fertility management tools to monitor short-term changes in SOM quantity and quality (MARRIOTT; WANDER, 2006; KALAMBUKATTU et al., 2013). Kalambukattu et al. (2013) evaluated the labile fraction of SOM under different land use and management in the central Himalayan region and observed higher levels in forest and organic farming soils, compared to soils under soybean and wheat cultivation. Guimarães et al. (2014) reported a higher concentration of particulate organic matter in forest soil than in soils under banana and citrus cultivation in northeast Brazil. Loss et al. (2009) determined total organic carbon and particulate organic matter in soils under a no-till planting system (NTI) and an integrated crop and livestock system (CLI) in the cerrado region of Goiás State, Brazil, and observed that the CLI system was more effective in increasing SOM and improving soil quality.

In order to demonstrate how the different SOM pools can be related to soil quality and management, Blair et al. (1995) determined the labile and stable SOM fractions in a series of paired soil samples collected from cultivated and uncultivated sites in three regions of northern and central New South Wales, Australia, and constructed a carbon management index (CMI). The approach used was based on the dependence that the continuity of carbon supply has on both the size of the total carbon pool and the contribution of the labile fraction, which therefore had to be taken into account in generating the CMI. Vieira et al. (2007) successfully applied a CMI to an Acrisol in southern Brazil. However, studies using this index in the northeast region of Brazil are scarce.

The objectives of this work were to evaluate the effect of the application of composted and non-composted organic residues on the distribution of the soil organic carbon (SOC) pools, considering total SOC, particulate organic matter (POM), and mineral-associated organic matter (COM) in the soil of a six-year-old citrus orchard. A CMI was constructed using the labile and stable carbon pools.

MATERIAL AND METHODS

Site characterization and experimental design

The fieldwork was conducted between March 2011and July 2012 in an area cultivated with citrus (*Citrus sinensis* L. Osbeck) in Umbaúba, State of Sergipe (11º 22’ 32”S, 37º 39’ 35”W), in northeast Brazil. The climate of the region is BSh type, according to the Köppen-Geiger classification (PEEL et al., 2007), with dry summers and rainfall concentrated in the period from May to September. The mean annual precipitation and temperature are 1601 mm and 25 °C, respectively. The soil at the site was classified as Argissolo Amarelo (SANTOS et al., 2013; SOIL SURVEY STAFF, 2014) . The relief was flat to slightly undulating, and the site had been planted with citrus for over 30 years.

Initial soil samples were collected from the 0-0.20 m layer at the experimental site prior to application of the treatments. Soil texture was determined using the hydrometer method, pH was measured using a 1:2.5 soil/solution ratio, available P was extracted using Mehlich 1 solution, and the CEC was calculated from the sum of cations (SILVA, 2009). The soil texture was analyzed according to Donagema et al. (2011) and was found to be 76.1 % sand, 3.4 % silt, and 20.5 % clay. The soil pH was 6.50, extractable P was 13.7 mg kg^{-1}, and the CEC was 8.60 $cmol_c$ kg^{-1}.

The experimental design (Figure 1) consisted of six treatments in which the organic residues and their associations were assigned as whole plots, and the sampling depths as subplots, with three replicates. The treatments consisted of:

1.NCOR: Non-composted organic residues, applied in alternated layers as follows (in order, from the bottom upwards): manure (50 L) + Gafsa rock phosphate (300 g) + ground coconut crop residues (150 L) + manure (50 L) + Gafsa rock phosphate (300 g) + ground corn straw (200 L). Gafsa rock phosphate is a natural rock phosphate containing 28 % P_2O_5.

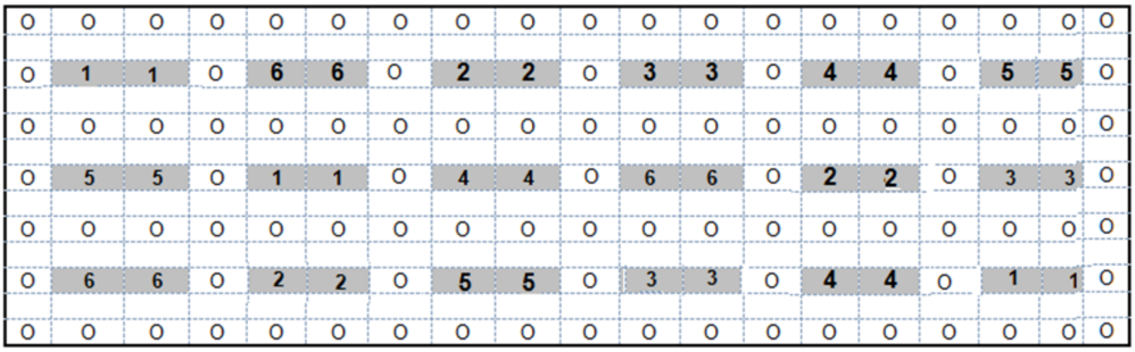
2.NCOR + NPK: Non-composted organic residues, applied in the same order as described for treatment 1, plus NPK (500 g of urea, 500 g of simple superphosphate, and 500 g of KCl).

3.Humus: Composted organic residue prepared previously using the same crop residues, manure, and phosphate fertilizer, applied at a rate of 100 L per plant.

4.Humus + NPK: 100 L of composted organic residue, as described for treatment 4, plus NPK (500 g of urea, 500 g of simple superphosphate, and 500 g of KCl).

5.Control + NPK: Without application of organic residues, but with NPK (500 g of urea, 500 g of simple superphosphate, and 500 g of KCl).

6.Control: Without application of organic residues or NPK.



O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
O	1	1	O	6	6	O	2	2	O	3	3	O	4	4	O	5	5	O
O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
O	5	5	O	1	1	O	4	4	O	6	6	O	2	2	O	3	3	O
O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
O	6	6	O	2	2	O	5	5	O	3	3	O	4	4	O	1	1	O
O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O

Figure 1. Design of the experimental plot. * O = plant; Numbers represent the treatments (1: NCOR – NPK; 2: NCOR + NPK; 3: Humus – NPK; 4: Humus + NPK; 5: Control + NPK; 6: Control – NPK). Space between plants: 6 x 4 m.

The cow manure provided by the farmer was collected in the animal management area and had the following characteristics: pH 5.3, 25 % humidity, 30 g C kg^{-1}, 1.42 g N kg^{-1}, 4.0 g P kg^{-1}, and 3.11 g K kg^{-1} (SILVA, 2009). The humus was prepared at the property and contained 20 g C kg^{-1}, 2.3 g N kg^{-1}, and 110 g P kg^{-1}, with pH 7.0.

The treatments were applied in February of 2011 and 2012. The experiment followed a completely randomized block design where two plants composed an experimental unit (Figure 1), with three replicates (six plants). The organic residues and mineral fertilizers were applied manually under the circumference of the plant canopy.

Soil samples were collected from three depths (0-0.05, 0.05-0.10, and 0.10-0.15 m) in September 2012. At each depth, six simple samples were collected and then mixed to form a composite soil sample. The samples were transported in plastic bags to the laboratory, where they were air-dried, sieved through a 2 mm screen, and stored for later analysis.

Soil organic carbon fractions

Total soil organic matter was determined by the Walkley-Black method (NELSON; SOMMERS, 1996). Particulate organic matter (POM-C) was determined by physical fractionation according to Cambardella and Elliot (1992). For this, 20 g of the air-dried 2 mm sieved soil samples were placed in 250 mL plastic bottles, followed by addition of 70 mL of sodium hexametaphosphate at a concentration of 5.0 g L^{-1}. The mixture was shaken for 15 h in a horizontal shaker at 130 oscillations min^{-1}. After this process, the entire content of the bottle was placed on a 53 µm sieve and washed with a weak jet of distilled water. The material retained on the sieve, defined as total particulate organic matter (POM-C, > 53 µm), was dried at 50 °C. After drying, the sample was ground in a porcelain mortar and passed completely through a 0.149 mm sieve. The content of complexed organic matter (COM-C) was determined from the difference between the total organic C pool and the POM-C pool.

Aliquots of the fraction were weighed and analyzed to determine the C and N contents, representing POM-C and the N in particulate organic matter (PN) (CAMBARDELLA; ELLIOT, 1992). The soil analyses were performed using three replicates.

Soil samples were also obtained from an undisturbed remnant of the Atlantic forest with native vegetation, near the experimental area, which had the same landscape, relief, and soil type. The protocol used was the same as for collection of samples from the experimental plot. Based on the TOC values for the soils from the native forest (reference) area and the citrus orchard, a carbon pool index (CPI) was obtained as follows: $CPI = TOC_{\text{orchard area}}/TOC_{\text{native forest}}$. According to changes in the proportions of labile (POM) and non-labile (COM) organic C (LC and NLC, respectively) in the soil (i.e., L = LC/NLC), a lability index (LI) was calculated as: $LI = L_{\text{orchard area}}/L_{\text{native forest}}$. These two indices were used to determine the carbon management index (CMI), according to the methodology used by Vieira et al. (2007) and Guimarães et al. (2014), in both cases adapted from Blair et al. (1995), who employed the oxidizable fraction of SOM, instead of the physical fraction. The following equation was used: $CMI = CPI \times LI \times 100$.

Statistical analysis

The data were analyzed following a randomized block design and using subplots. The treatments and sampling depths were considered as primary and secondary effects, respectively. The results were submitted to analysis of variance for identification of relevant effects, and the means were compared using the Scott-Knott test ($p < 0.50$). All these analyses were performed using SISVAR v. 5.0 software (FERREIRA, 2003).

RESULTS AND DISCUSSION

Total organic carbon (TOC)

The soil total organic carbon contents are provided in Table 1. For the soils that received the organic treatments, the TOC contents were highest in the surface layers, as expected because the surface soil contained most of the organic components as well as higher microbial populations and activities. Compared to the control without fertilizer, increments of 10.3, 22.4, 16.3, and 37.1% were found for the TOC contents of the NCOR – NPK, NCOR + NPK, humus + NPK, and humus – NPK treatments, respectively, in the 0-0.05 m soil layer. The TOC values for the deeper layers showed no significant differences among the treatments.

In order to effectively increase SOM, the rate of input must exceed the rate of loss due to decomposition and leaching processes. In most agricultural cases, this is achieved by stubble retention, rotating crops with pasture, or the addition of organic residues such as animal manure and litter. However, significant improvements in the organic matter contents of tropical soils are limited by the soil and climate. In the present study, the results were from a 2-year trial, so it is likely that higher SOM levels would be achieved after longer periods. Lopes et al. (2012) evaluated the SOM content of a Cambissolo Eutrófico (Inceptisol) in the State of Ceará, which was cultivated with melon for between 3 and 10 years using conservative management practices such as crop rotation and incorporation of crop residues. It was observed that after 10 years of cultivation, the SOM content was preserved in the surface soil and increased in the deeper layers. In contrast, Martins et al. (2015) studied the SOM contents of samples of different soil classes collected under deciduous formations in the States of Minas Gerais and Bahia, and observed decreases of SOM with depth.

In the present case, addition of NPK alone resulted in a homogeneous distribution of TOC among the three soil layers evaluated. Besides the absence of organic residues in this treatment, the even distribution of TOC with depth could have been due to the high solubility of the mineral fertilizer, as compared to the other treatments, which influenced SOM mineralization. Therefore, the addition of mineral fertilizer alone did not improve soil quality and might even have favored mineralization of the native soil organic matter.

Particulate (POM) and complexed (COM) organic matter fractions

The application of organic residues, alone or in combination with mineral fertilizer, resulted in higher values of the POM fractions than the other treatments, especially in the 0-0.05 m layer (Table 1). The humus – NPK treatment resulted in the highest concentration of POM (12.8 g kg^{-1}) in the surface layer. The lowest values for the surface layer were observed for the control (3.0 g kg^{-1}) and NPK (3.6 g kg^{-1}) treatments (Table 1). These results suggest that the POM content was related to the quantity and nature of the organic inputs applied to the soil surface, as reported elsewhere (CARMO et al., 2012; ROSSI et al., 2012a). The presence of POM is often beneficial to the soil due to its ability to supply plant nutrients and stimulate microbial activity (CULMAN et al., 2013). In addition, the POM fraction improves soil aggregation and consequently increases aeration as well as the infiltration, flow, and retention of water (KOLAR et al., 2009; VERHULST et al., 2010); However, there is also the possibility that the loss of carbon from the soil could increase, due to the rapid turnover time of this labile fraction (VERHULST et al., 2010). According to Kolar et al. (2009), the least stable fractions of SOM, which are easily decomposable, are the most valuable and are considered an important indicator of soil quality.

Overall, the contribution of the POM fraction was lower than that of the COM fraction, as is common for cultivated soils such as the one used here. Based on the mean values for all the treatments, the percentages of C in the POM fraction were 40, 27, and 26 % for the 0-0.05, 0.05-0.10, and 0.10-0.15 m layers, respectively (Figure 2). However, the application of organic residues also influenced the proportion of the POM fraction.

Table 1. Total soil organic carbon (TOC) and the labile (POM) and complexed (COM) fractions of soil organic matter in an Ultisol treated two years earlier with non-composted organic residues (NCOR) and composted organic residues (humus), with and without fertilizer, in a citrus orchard in Brazil.

Treatments	Soil depth (m)		
	0-0.05	0.05-0.10	0.10-0.15
		TOC ($g\ kg^{-1}$)	
Control - NPK	11.6A*b**	12.0 Aa	8.5 Ba
Control + NPK	10.9 Ab	10.3 Aa	8.6 Aa
NCOR - NPK	12.8 Ab	10.6 Ba	9.9 Ba
NCOR + NPK	14.2 Aa	9.4 Ba	10.0 Ba
Humus - NPK	15.9 Aa	12.3 Ba	10.4 Ba
Humus + NPK	13.5 Aa	10.0 Ba	7.9 Ba
		POM ($g\ kg^{-1}$)	
Control - NPK	3.0 Ad	2.2 Ab	1.0 Bc
Control + NPK	3.6 Ad	2.6 Ab	2.6 Ab
NCOR - NPK	8.7 Ab	5.0 Ba	4.6 Ba
NCOR + NPK	7.2 Ac	4.6 Ba	5.9 Ba
Humus - NPK	12.8 Aa	3.8 Ba	3.3 Bb
Humus + NPK	6.8 Ac	4.2 Ba	2.6 Bb
		COM ($g\ kg^{-1}$)	
Control - NPK	8.6 Aa	9.7 Aa	7.6 Aa
Control +NPK	7.3 Aa	7.7 Aa	6.0 Aa
NCOR - NPK	4.2 Ab	5.7 Ab	5.2 Aa
NCOR + NPK	7.0 Aa	4.8 Ab	4.1 Aa
Humus - NPK	3.1 Bb	8.5 Aa	7.2 Aa
Humus + NPK	6.7 Aa	5.7 Ab	5.3 Aa

(*) Means within rows at different depths followed by the same capital letter, and (**) means within columns at the same depth followed by the same lower case letter, are not significantly different according to the Scott-Knott test ($p < 0.05$).

In the surface layer, the proportion of the POM fraction followed the order: humus = NCOR – NPK > NCOR + NPK = humus + NPK > control + NPK = control – NPK (Figure 1a). The results suggest that the addition of mineral fertilizer accelerated SOM decomposition and therefore decreased the labile C fraction. The lowest POM fraction proportions obtained for the control – NPK (19 %) and control + NPK (26 %) treatments were expected due to the absence of organic residue inputs. In the 0.05-0.10 m layer, the POM fraction proportion followed the order: NCOR + NPK = NCOR – NPK = humus + NPK > humus – NPK > control + NPK = control – NPK (Figure 1b). In the 0.0.10-15 m layer, the POM fraction proportion followed the order: NCOR + NPK = NCOR – NPK > humus + NPK = humus – NPK = control + NPK = control – NPK (Figure 1c).

Leite et al. (2003) evaluated the effects of compost and mineral fertilization in Ultisols under agricultural use in the southeastern Brazilian State of Minas Gerais, a region of lower temperatures and higher annual precipitation rates, and observed increases in organic C pools in the areas treated with organic residues. However, the authors reported decreases in the labile C pools, particularly where no organic residue was added. These results explain why it is harder for farmers and land managers to maintain the quality of SOM, compared to increasing its quantity in cultivated soils. Rossi et al. (2012a) applied organic residues (sorghum straw and grass-based residues) to the soil surface in the State of Goiás, in central-west Brazil, and observed significant changes in the particulate organic matter fraction. Marriot and Wander (2006) studied labile and stable fractions of organic matter in soils from nine long-term trials, comparing manure + legume-based organic, legume-based organic, and conventional farming systems in different regions of the United States. The authors observed substantial increases in the labile SOM (POM) contents of soils under manure and legume-based organic management. In contrast, Aguiar et al. (2013) used physical fractionation to evaluate the effects of different land uses in the humid tropical Amazon region on the dynamics of SOM. It was found that there was a significant reduction in the particulate organic matter fraction when the soil was intensively and continuously cultivated with annual crops.

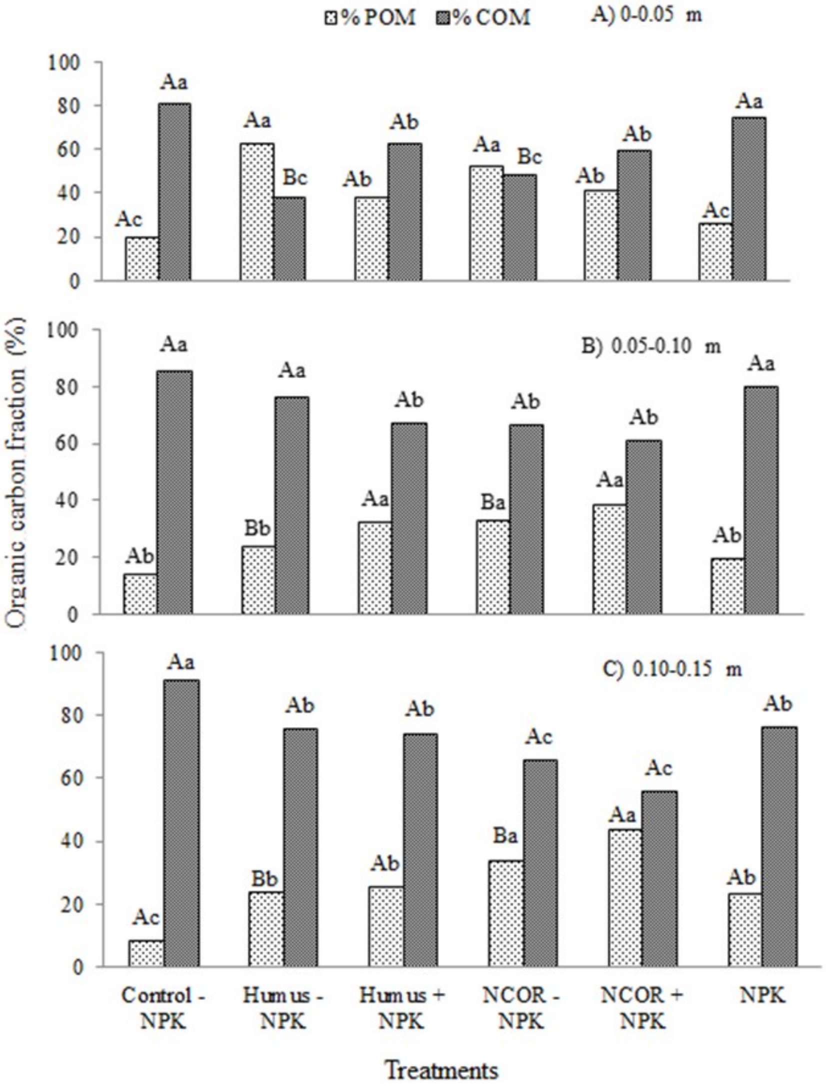


Figure 2. Percentages of total organic carbon in the forms of particulate (POM) and complexed (COM) organic matter in different layers of an Ultisol treated two years earlier with non-composted organic residues (NCOR) and composted organic residues (humus), with and without NPK, in a citrus orchard in Brazil.

For all the treatments, high proportions of the COM fraction were maintained in all the soil layers (Figure 2). A long-term effect of the application of organic residues to the soil can be an increase of the stable SOM pool composed of weakly decomposable organic compounds, which can have several beneficial and enduring effects in terms of soil improvement and conservation (TERMORSHUIZEN; VAN RIJN; BLOK, 2005). The association of COM with the mineral matrix prevents rapid decomposition and extends the turnover time beyond that dictated by its chemistry. In addition, a high proportion of the COM fraction is important because it represents a pool of C that can provide a high degree of protection for the soil. Aoyama, Angers and Dayegamiye (1999) followed the effects of long-term (18 years) application of manure and NPK fertilizer on organic matter fractions in the 0-0.10 m layer of a Humic Gleysol in Quebec, Canada, concluding that manure application contributed to greater accumulation of protective carbon, compared to the application of NPK alone. Historical losses of SOM due to inappropriate land use and poor management practices cause soil quality to decline, while practices that lead to increase of the soil C reserve are strongly encouraged in order to improve soil organic C stocks, soil quality, and land sustainability.

The proportions of the POM and COM fractions were within the normal ranges for most soils. According to Cambardella and Elliot (1992), the POM and COM fractions contribute 10-30 % and 70-90 %, respectively. It is important that these proportions are kept in balance in order to preserve both the quality of the soil and the carbon stock. Because of its short turnover time, an adequate POM content ensures the availability of nutrients and energy for biological processes. The POM fraction is often considered the most important SOM component for providing nutrients to plants. However, the presence of POM at a higher proportion than COM can potentially lead to significant losses of soil organic carbon. In the present case, application of humus and NCOR increased the proportion of POM in the surface soil, relative to the COM fraction, forming a fragile organic C reserve.

The results of this study show the importance of analyzing different soil carbon fractions, particularly when monitoring changes in land use and management.

Soil carbon management index (CMI)

The determination of the CMI is preceded by calculation of the carbon pool index (CPI) and the lability index (LI), and enables evaluation of the quality of soils under different land uses and management.

The CPI values ranged from 0.7 to 1.1 (Table 2) and were highest for the humus treatment, probably due to the greater contribution of the POM fraction. The LI values varied from 0.2 to 2.3, with mean values for the three soil depths in the order: NCOR + NPK (1.53) > NCOR – NPK (1.16) = humus – NPK (1.13) > humus + NPK (0.9) > control (0.3).

The CMI values for the different treatments were in the ranges 21.3-149.9 (surface layer), 37.1-100.8 (0.05-0.10 m layer), and 11.2-132.5 (0.10-0.15 m layer) (Table 2). In general, irrespective of the soil depth, the CMI values were in the order: NCOR – NPK > NCOR + NPK > humus – NPK > humus + NPK > control + NPK > control – NPK.

Table 2. Index values for the Ultisol treated two years earlier with non-composted organic residues (NCOR) and composted organic residues (humus), with and without fertilizer, in a citrus orchard in Brazil. Carbon pool index (CPI) = $TOC_{orchard}/TOC_{native\ forest}$; Carbon lability index (LI) = $L_{orchard}/L_{native\ forest}$; Carbon management index (CMI) = CPI x LI x 100.

Treatments	Soil depth (cm)		
	0-5	5-10	10-15
		CPI	
Control - NPK	0.8 Aa	1.0 Aa	0.8 Aa
Control+NPK	0.7 Aa	0.9 Aa	0.8 Aa
NCOR - NPK	0.8 Aa	0.9 Aa	0.9 Aa
NCOR + NPK	0.9 Aa	0.8 Aa	0.9 Aa
Humus - NPK	1.0 Aa	1.1 Aa	1.0 Aa
Humus + NPK	0.9 Aa	0.9 Aa	0.7 Aa
		LI	
Control - NPK	0.3 Ac	0.4 Ac	0.2 Ac
Control + NPK	0.4 Ac	0.7 Aab	0.7 Ab
NCOR - NPK	1.2 Aa	1.2 Aa	1.1 Ab
NCOR + NPK	0.8 Bb	1.5 Aa	2.3 Aa
Humus - NPK	1.8 Aa	0.8 Aab	0.8 Ab
Humus + NPK	0.6 Ab	1.4 Aa	0.7 Ab
		CMI	
Control - NPK	21.3 Be	44.2 Ae	11.2 Ce
Control + NPK	33.4 Bd	37.1 Be	44.0 Ad
NCOR - NPK	71.1 Cb	90.0 Bb	132.6 Aa
NCOR + NPK	72.4 Bb	100.8 Aa	105.1 Ab
Humus - NPK	149.9 Aa	67.5 Bc	49.2 Cd
Humus + NPK	52.8 Ac	58.4 Ad	60.0 Ac

(*) Means within rows at different depths followed by the same capital letter, and (**) means within columns at the same depth followed by the same lower case letter, are not significantly different according to the Scott-Knott test ($p<0.05$).

According to Blair et al. (1995), CMI values above 100 are indicative of positive impacts of land management practices on the SOM content and soil quality. In earlier work, this index was found to be effective in detecting changes in soil organic matter status in the short to medium term, which was not observed when only the TOC content was used (DIEKOW et al., 2005).

Both the soil organic carbon contents and the CMI values increased for the treatment with fresh organic residues and farmyard manure dispersed in layers on the soil surface. Values consistently higher than 100 were observed for the 0.10-0.15 m layer when the NCOR treatment was applied, regardless of the presence of NPK, showing the superiority of that treatment, which was probably related to the presence of organic residues that decomposed rapidly. In the case of the humus treatment, the CMI values for the first 0.05 m soil depth were above the critical limit, which appeared to be related to the presence of fertilizer as well as the stability of the humus.

The mean CMI value for the three layers evaluated did not exceed the 100 threshold suggested by Blair et al. (1995), who reported values mostly lower than 100 for soil samples from Australia and Brazil, which appeared to be related to the crop period. The CMI values were only higher than 100 for Brazilian soil samples from a site treated with mulching for 12 months, a situation closer to that of the present study. Blair et al. (1995) pointed out that although the CMI provides a good indication of the rate of change in soil C dynamics over time, or when using a more stable soil as a reference, there is no ideal value.

CONCLUSIONS

The application of non-composted organic residues in layers alternated with animal manure and natural phosphate showed results comparable to the application of composted organic residues (humus), with an increase in the total organic carbon content of the citrus orchard soil, especially when the treatment was used in combination with mineral fertilizer. However, in the case of the labile organic matter fraction, the inclusion of mineral fertilizer with either of the organic residue treatments reduced the POM fraction and increased the stable organic matter fraction. The physical fractions of SOM were more effective in indicating differences among treatments, compared to the measurement of total organic carbon. This was confirmed by determination of the CMI, which helped to improve understanding of the benefits of application of organic residues and mineral fertilizer to the soil studied.

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