

Carbon fractions and soil fertility affected by tillage and sugarcane residue management of a Xanthic Udults

Frações do carbono e fertilidade do solo afetados pelo preparo do solo e manejo da palhada da cana-de-açúcar em Argissolo Amarelo

Iara Maria Lopes^{1*}; Shirlei Almeida Assunção¹; Ana Paula Pessim de Oliveira²; Lúcia Helena Cunha dos Anjos³; Marcos Gervasio Pereira³; Eduardo Lima³

Abstract

The gradual change in management practices in sugarcane (*Saccharum spp.*) production from burning straw to a green harvesting system, as well as the use of minimum soil tillage during field renovation, may affect soil fertility and soil organic matter (SOM) contents. The objectives of this work were to investigate the influence of sugar cane production systems on: (1) soil fertility parameters; (2) on physical carbon fractions; (3) and on humic substance fractions, in a long-term experiment, comparing two soil tillage and two residue management systems an Xanthic Udult, in the coastal tableland region of Espírito Santo State, Brazil. The treatments consisted of plots (conventional tillage (CT) or minimum tillage (MT)) and subplots (residue burned or unburned at harvesting), with five replicates. The highest values of $\text{Ca}^{2+} + \text{Mg}^{2+}$ and total organic carbon (TOC) were observed in the MT system in all soil layers, while high values of K^+ were observed in the 0.1-0.2 m layer. The CT associated with the burned residue management negatively influenced the TOC values, especially in the 0.1-0.2 and 0.2-0.4 m layers. The carbon in the humin fraction and organic matter associated with minerals were significantly different among the tillage systems; the MT showed higher values than the CT. However, there were no significant differences between the sugarcane residue management treatments. Overall, fractioning the SOM allowed for a better understanding of tillage and residue management systems effects on the soil properties.

Key words: *Saccharum spp.* Soil tillage systems. Residue retention.

Resumo

A mudança gradual nas práticas de manejo da cana de açúcar (*Saccharum spp.*) de colheita com queima de palha para o sistema de colheita sem queima, bem como o uso de preparo mínimo do solo durante a renovação do canavial, podem afetar a fertilidade do solo e o conteúdo de matéria orgânica do solo (MOS). Os objetivos específicos foram investigar a influência de sistemas de produção de cana-de-açúcar sobre: (1) os parâmetros de fertilidade do solo; (2) sobre as frações físicas do carbono; (3) e em frações de substâncias húmicas, em um experimento de longa duração, comparando dois tipos de preparo do solo e dois sistemas de manejo da palhada em Argissolo Amarelo, na região tabuleiros costeiros do Espírito Santo, Brasil. Os tratamentos consistiram de parcelas (preparo convencional (PC)

¹ Discentes, Curso de Doutorado, Programa de Pós-Graduação em Agronomia, Ciência do Solo, Departamento de Solos, Universidade Federal Rural do Rio de Janeiro, UFRRJ, Seropédica, RJ, Brasil. E-mail: iara_m_lopes@hotmail.com; shirleiaagro@gmail.com

² Dr., Pós-Doutorando do Curso de Pós-Graduação em Ciência, Tecnologia e Inovação em Agropecuária, UFRRJ, Seropédica, RJ, Brasil. E-mail: ppessim@yahoo.com.br

³ Profs., Departamento de Solos, UFRRJ, Seropédica, RJ, Brasil. E-mail: lanjorsrural@gmail.com; mgervasiopereira@gmail.com; ardolima2@terra.com.br

* Author for correspondence

e cultivo mínimo (CM)) e subparcelas (palha queimada e não queimada perante a colheita), com cinco repetições. Foram observados os maiores valores de $\text{Ca}^{2+} + \text{Mg}^{2+}$ e carbono orgânico total (COT) no sistema de CM, em todas as camadas do solo, enquanto maiores valores de K^+ foram observados na camada de 0,1-0,2 m. O PC associado a colheita com queima da palhada influenciou negativamente os valores de COT, especialmente nas camadas 0,1-0,2 e 0,2-0,4 m. O carbono na fração húmica e o carbono associado aos minerais do solo foram significativamente diferentes entre os sistemas de preparo do solo; o CM apresentou valores mais elevados do que o PC. No entanto, não houve diferenças significativas entre o manejo da palhada da cana-de-açúcar. No geral, o fracionamento da MOS permitiu uma melhor compreensão dos efeitos dos sistemas de preparo do solo e manejo da palhada sobre as propriedades do solo.

Palavras-chave: *Saccharum spp.* Sistemas de preparo do solo. Manutenção da palhada.

Introduction

Sugarcane (*Saccharum spp.*) production is one of the most economically important agricultural activities in Brazil, both for sugar and ethanol production. In 2014, the cultivated area was slightly over 9 million hectares (CONAB, 2014) and approximately 65% of the sugarcane was harvested without previous burning the dead leaves (CANASAT, 2014), a practice traditionally used to facilitate the stem harvesting. In Brazil, the no burning prior to harvesting is known as green cane harvesting (GCH), and this practice is expected to be adopted by almost all the mechanized sugarcane production areas by the end of this decade. The GCH system adds 10 to 20 t ha⁻¹ yr⁻¹ of crop residues (dry leaves, tops and pieces of stalks) to the surface, which has the potential to affect soil water and nutrient dynamics and soil properties (ROBERTSON; THORBURN, 2007), index richness of soil fauna (BENZAZZI et al., 2013), changing the potential crop yield. For this reason, GCH and other tillage management strategies should be investigated in the different production regions of Brazil.

Systems with less intense tillage operations, such as minimal tillage and no-tillage, associated with residue retention (instead of burning the sugarcane residues), provide modifications on dynamics of essential nutrients and toxic elements when compared to the conventional tillage (CT) system. Besides provide potential benefits to environment, such as increased soil organic carbon (SOC) and the reduction of atmospheric pollution (HOUX et al.,

2011; SEGNINI et al., 2013). However, in a wide of areas with sugarcane production, conventional tillage operations, such as plowing, disking and subsoiling, are still widely used (SEGNINI et al., 2013).

When minimal tillage and no-tillage is adopted the soil is less disturbed and nutrients such as phosphorus, potassium, calcium, and magnesium, are strongly adsorbed to the soil colloids functional groups (CALEGARI et al., 2013). Some studies have shown that exchangeable Ca, Mg, and K were significantly higher in the surface soil under minimum tillage when compared to areas of ploughed soil and where the sugarcane straw is kept on soil surface (OLIVEIRA et al., 2002; ROSOLEM et al., 2007; RAHMAN et al., 2008).

Studies in different regions of the world show that adoption of harvest system without straw burning increase total soil organic, observed in the studies of Robertson and Thorburn (2007) in Australia, and Galdos et al. (2009) in Brazil. On the other hand, in some sugarcane systems, the SOC concentration was not significantly different among sites where sugarcane residues were burned or retained, such as in Brazil and Australia (BLAIR, 2000) and in Africa (GRAHAM et al., 2002). According to Thorburn et al. (2012) the absence of differences in the SOC are possibly due to cultivation and variation in bulk density between treatments, as well as difficulties in detecting small changes in total soil organic matter or organic carbon because of generally high background levels and natural soil variability.

Some authors state that the effect of changes in land use and soil management on SOC, even in a short period of time, may be identified by variations in the sub pools or fractions of soil organic matter or organic carbon, which are more noticeable than the TOC (GALDOS et al., 2009; PINHEIRO et al., 2015; THORBURN et al., 2012).

Granulometric fractionation of the SOM by particle size separates the material into sand size fractions: particulate organic carbon (>53 μm) and carbon in the organic matter associated with the minerals of silt (2-53 μm) and clay (0-2 μm) sizes. This procedure may be applied to evaluate the dynamics of the total organic carbon (TOC), even for short-term changes. Particulate organic matter is closely related to the crop residue added to the soil surface and is sensitive to changes in management, and the fraction associated with minerals typically represents most of the soil C (BLANCO-MOURE et al., 2013; CAMPOS et al., 2011). Chemical fractionation separates the material into humic acids, fulvic acids, and humin. The great amount of acid groups in the humic and fulvic acids influence positively soil cation exchange, and the association of compounds in humin fraction with soil mineral colloids imparts resistance to biodegradation of SOM (YAGI et al., 2005).

The reduction of organic matter resulting from soil degradation is particularly relevant in soils of the coastal tablelands, a prominent landscape that has great importance for agricultural production of sugarcane, mainly in the northeastern region of Brazil. The soils of this region typically have low fertility and may present cohesive horizons below the arable layer. The clay mineralogy is kaolinitic, and the cation exchange capacity is highly dependent on soil organic carbon content (CORRÊA et al., 2008). Among the crops most cultivated in Coastal Tablelands, sugarcane is dominant due to climatic conditions and show a slightly undulating relief. The burnt cane harvesting system and the conventional tillage operations are still common practices.

The minimum tillage and sugarcane residues are retained instead of burned positively changes in carbon fractions and soil fertility. The objectives of this work were to investigate the influence of sugar cane production systems on: (1) soil fertility parameters; (2) on physical carbon fractions; (3) and on humic substance fractions, in a long-term experiment, comparing two soil tillage and two residue management systems, in the coastal tableland region of Espírito Santo State, Brazil.

Material and Methods

Soil samples were collected from a pre-existing experiment located on a sugarcane farm in the Linhares municipality, Espírito Santo (southeast region of Brazil, 19° 18'S and 40° 19' W). The landscape is characterized by a gently undulating relief with low plateaus that define the "tabuliform relief," a geomorphological feature of the coastal tablelands. The original vegetation was the Atlantic Forest. The climate shows that 70 to 80% of the total precipitation (1000-1250 mm) falls from October to April. The average annual temperature ranged from 22 to 24 °C during the 21 years of the experiment. The soil is a sandy over loamy texture Xanthic Udult (*Argissolo Amarelo*). The granulometry was determined for each soil depth increment (Table 1) (EMBRAPA, 1997).

The experimental site, originally covered with secondary forest, was cleared, and a pasture of *Brachiaria spp.* was planted in 1986. The experiment was initiated in 1989 and set in a randomized block design with five replicates. Initially, the experiment was divided into two treatments: green cane harvesting (with residue retained as a surface mulch or blanket) and a harvesting system in which the residue was burned annually. The site was managed under conventional tillage (CT) with one plowing, two heavy disking operations and opening of furrows in the soil up to a 0.3 m depth. The 10 plots consisted of 6 rows of sugarcane (95 m in length) spaced at 1.2 m between the rows. The sugarcane

(*Saccharum spp.*) variety used was the SP79-1011, and the first crop cycle (plant + ratoons cane) ended in 1996. Seven months after manual harvesting, the experimental site was reduced in half and two new treatments were inserted within the original green and burnt cane plots. The experimental design was a randomized block design, with a subdivision plots scheme with five replicates, allocated to compare two soil tillage treatments (CT or minimum tillage

(MT)) and two sugarcane residue treatments (residues burned or unburned at each harvest). The new plots had an area of 286 m² and contained 11 rows (22 m in length) with spacing of 1.2 m between the lines. From 1997 to 2012 there were two crop cycles. Lime, nitrogen, phosphorus and potassium fertilizers were applied. The RB73 9735 and SP79-1011 cane varieties were used, and both were manually harvested.

Table 1. Granulometry for each soil depth increment in the long-term sugarcane experiment, Linhares-ES climate, Xanthic Udult soil.

Soil layers (m)	Sand	Silt	Clay
 g kg ⁻¹		
0.0-0.1	852	53	94
0.1-0.2	850	47	106
0.2-0.4	824	53	122

For this study samples were taken after harvesting of the sixth ratoon in 2012; thus corresponding to approximately 23 years after the experiment start and first soil management practices, and 15 years after the combination of the two soil tillage treatments and two sugarcane residue treatments. The soil was sampled at 0-0.1, 0.1-0.2, and 0.2-0.4 m depths; taking three samples at each depth and forming a composite sample with six replicates for each treatment evaluated. The samples were identified, conditioned in plastic bags, and taken to the laboratory, where they were air dried and sieved using a 2 mm mesh.

The soil fertility attributes, pH, available phosphorus, potassium, sodium, calcium, magnesium, exchangeable aluminum and potential acidity were quantified using the procedures described by EMBRAPA (1997). The TOC was quantified according to the method of Yeomans and Bremner (1988). The granulometric fractioning of the SOM, in the samples from 0-0.1 m depth, was quantified after mixing 20 g of soil in 60 ml of sodium hexametaphosphate solution (5 g l⁻¹) and separating the sand from the silt and clay fractions using a 53 µm sieve (CAMBARDELLA; ELLIOTT,

1992). The material retained in the sieve, which consisted of particulate organic matter (POM) associated with the sand fraction, was dried at 60 °C, quantified in relation to its mass, and ground in a porcelain mortar, and the organic carbon was analyzed according to the method of Yeomans and Bremner (1988). The material that passed through the 53 µm sieve, which consisted of organic matter associated to the minerals fractions (POM) in the silt and clay fractions, was calculated as the difference between the TOC and the POM.

The extraction and fractionation of humic substances, in the samples of the 0-0.1 m layer, were performed according to the differential solubility technique (SWIFT, 1996), adapted and presented by Benites et al. (2003). After fractionation, the organic carbon fractions in the fulvic acid (FA-C), humic acid (HA-C) and humin (HU-C) were quantified. A mass of soil with 30 mg of organic carbon was weighed and placed in contact with 20 ml of 0.1 NaOH mol L⁻¹ for 24 hours. The separation of the alkaline extract (AE = HA-C + FA-C) and the residue was accomplished by centrifugation at 5000 g for 30 minutes. The residue was reserved for the determination of humin (HU). The pH of the alkaline

extract (AE) was adjusted to 1.0 with 20% H₂SO₄, followed by decanting for 18 h. The precipitate (HA) was separated from the soluble fraction (FA) and filtered, and both volumes were increased to 50 ml with distilled water. The carbon fractions in the FA and HA were determined in 5.0 ml aliquots of extract, in which 1.0 ml of potassium dichromate (0.042 mol L⁻¹) and 5.0 ml of concentrated H₂SO₄ were added in a digester block heated to 150 °C (30 min). Subsequently, the mixture was titrated with ferrous ammonium sulfate (0.0125 mol L⁻¹) and the HU-C was measured in the residue. After the material was oven dried (65 °C up to complete drying), 5.0 ml of potassium dichromate (0.1667 mol L⁻¹) and 10.0 ml of concentrated H₂SO₄ were added and the solution was placed in a digester block heated to 150 °C (30 min). Then, the solution was titrated with ferrous ammonium sulfate (0.25 mol L⁻¹) (YEOMANS; BREMNER, 1988).

The resulting data were submitted to normality (Lilliefors) and homogeneity of variances (BARTLETT) tests. Subsequently, the results were analyzed for variance using F-test, and the average values compared by Duncan's test at 5% probability, using SAEG 9.1 (Sistema de Análises Estatísticas e Genéticas – UFV) statistical package. Additionally, the Pearson correlation method was used to evaluate influence of the treatments on soil chemical attributes of the 0-0.1 m layer.

Results

Soil chemical attributes

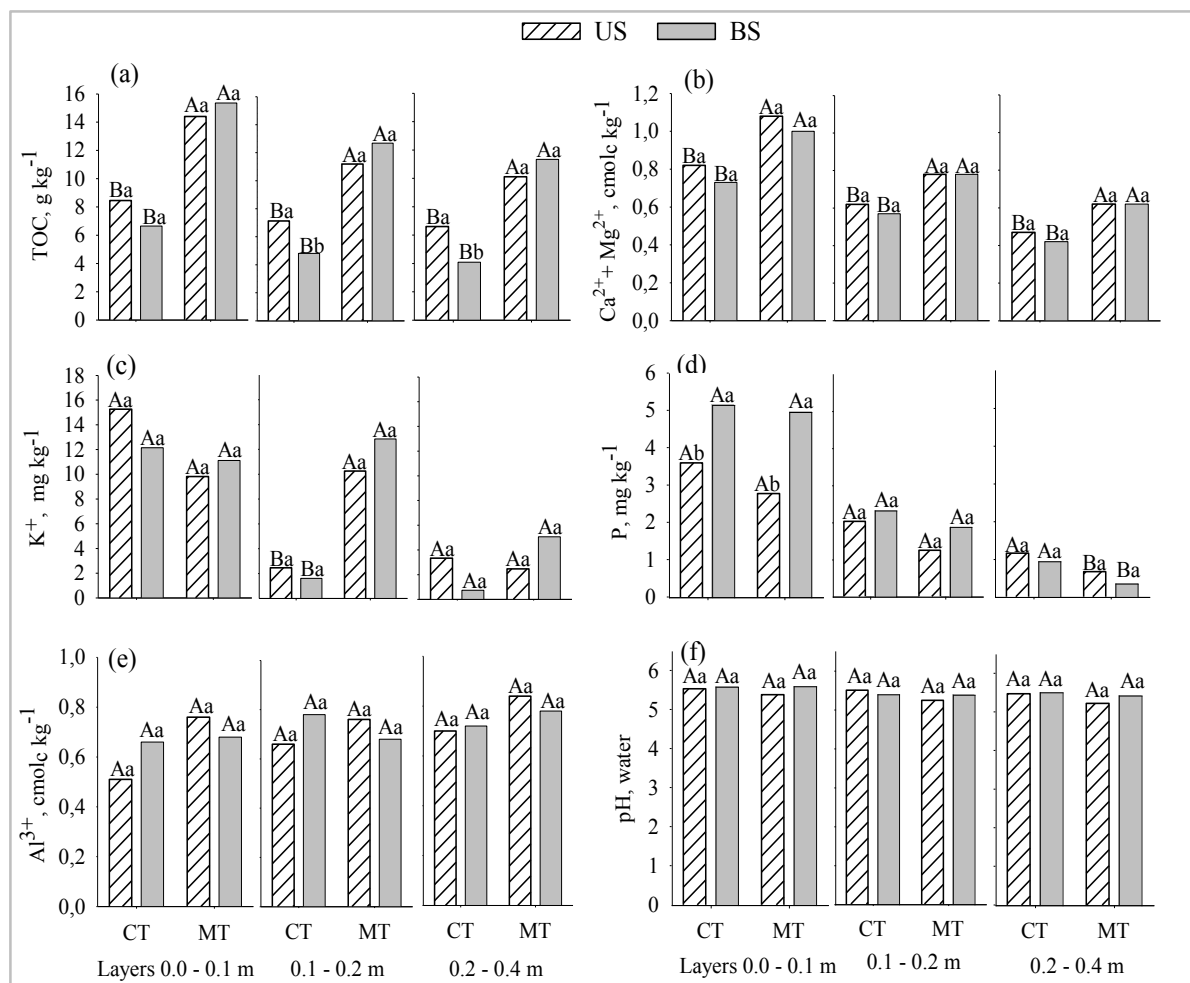
At the depths of 0.0-0.1, 0.1-0.2 and 0.2-0.4 m there was a significant difference in the TOC (Figure 1A) and Ca²⁺ + Mg²⁺ levels (Figure 1B) between the soil tillage systems. The MT showed an increase in the TOC content of approximately 100% compared

with the CT in all evaluated layers. MT increased Ca²⁺ + Mg²⁺ by 33%, 30% and 38% in the 0.0-0.1, 0.1-0.2 and 0.2-0.4 m layers, respectively (Figure 1B). Differences in K⁺ levels between soil tillage systems (Figure 1C) were observed only in the 0.1-0.2 m layer, and the MT resulted in an increase of more than 5 times than the CT.

The greatest amount of K⁺ in the MT (Figure 1C) is related to the higher content of TOC (Figure 1A), which increases the cation exchange capacity (CEC). Unlike K⁺, P has a low mobility in the soil; however, the soil tillage management (STM) showed significant differences in the available P (Figure 1D) in the 0.2-0.4 m layer. The levels of available P were low in all the soil layers (Figure 1D) (values ranging from 0.35 to 5.15 mg kg⁻¹), as commonly observed in Xanthic Udults. There was significant difference in the levels of available P in the 0-0.1 m layer with different sugarcane residue management treatments; the area with the burnt sugarcane increased 59% the values compared with the unburned sugarcane. There was no influence of the residue management system in other soil chemical properties.

Significant difference was verified for TOC in the 0.2-0.4 m layer, where the unburned sugarcane presented mean values 8% higher compared with the burnt treatment (Figure 1A). The interaction between soil tillage and residue management was not significant for the variables evaluated, with the exception of the TOC in the 0.1-0.2 and 0.2-0.4 m soil layers (Figure 1A). The MT did not influence residue management in the 0.1-0.2 and 0.2-0.4 m soil layers. However, the residue management associated with CT showed significant differences, with TOC 68 and 62% in the 0.1-0.2 and 0.2-0.4 m soil layers, respectively more in the unburned sugarcane compared to the burnt treatment.

Figure 1. Mean soil chemical properties in different soil tillage and residue management treatments in the sugarcane crop. MT: minimum tillage, CT: conventional tillage; BS: burnt sugarcane, US: unburnt sugarcane. Means followed by the same capital letter for soil tillage management and lowercase letters for the residue management did not differ significantly by the Duncan test at 5%.



Soil organic matter fractions

The distribution of carbon in the humic fractions (Table 2) showed larger amounts of HU-C compared to FA-C and HA-C for all treatments. In general, the comparison of residue management treatments (unburned and burnt treatments) did not show significant differences among fractions for the 0.0-0.1 m layer (HU, HA and FA). For soil tillage management, there was a difference in the C in all humic substance fractions (Table 2); MT showed the highest levels in comparison to CT, with values 82, 24 and 90% lower for the HU, HA and FA, respectively in the CT.

The particle size fractionation of SOM (Table 3) in the 0.0-0.1 m layer showed that in all treatments, the majority of the organic matter was associated with the soil minerals (MOM higher than POM). This result confirms the predominance of C in the humin fraction (Table 2). Among the tillage systems, the content of MOM was significantly different; the MT exhibited 144% more than the CT treatment. There were no differences in the particulate organic matter (POM) between the sugarcane management systems.

Table 2. Carbon in the humic substance fractions (humin = HU-C; fulvic acid = FA-C; humic acid = HA-C) in the 0.0-0.1 m layer under sugarcane management systems in a Xanthic Udult soil in Linhares (ES), Brazil.

Treatments	HU-C			FA-C			HA-C		
	US	BS	Mean	US	BS	Mean	US	BS	Mean
 (g kg ⁻¹).....								
CT	5.15 Ba	4.32 Ba	4.74 B	1.33 Ba	0.97 Bb	1.15 B	0.70 Ba	0.76 Ba	0.73 B
MT	8.41 Aa	8.85 Aa	8.63 A	1.35 Aa	1.49 Aa	1.42 A	1.49 Aa	1.19 Aa	1.34 A
Mean	6.78 a	6.59 a		1.34 a	1.23 a		1.09 a	0.97 a	

Means followed by the same capital letter in the lines for soil tillage management and lowercase letters in the columns for the residue management did not differ significantly by the Duncan test at 5%. Treatments: CT = Conventional Tillage; MT = Minimum Tillage; US = Unburned Sugarcane; and BS = Burnt Sugarcane.

Table 3. Particle size fractions of SOM (POM = particulate organic matter and MOM = organic matter associated to the mineral fractions) in the 0.0-0.1 m soil layer under sugarcane management systems in a Xanthic Udult soil in Linhares (ES), Brazil.

Treatments	MOM			POM		
	US	BS	Mean	US	BS	Mean
 (g kg ⁻¹).....					
CT	5.92 Ba	4.18 Ba	5.05 B	2.53 Aa	2.45 Aa	2.49 A
MT	11.56 Aa	13.09 Aa	12.32 A	2.86 Aa	2.26 Aa	2.56 A
Mean	8.74 a	8.64 a		2.70 a	2.36 a	

Means followed by the same capital letter in the lines for soil tillage management and lowercase letters in the columns for the residue management did not differ significantly by the Duncan test at 5%. Treatments: CT = Conventional Tillage; Minimum Tillage = MT; US = Unburned Sugarcane; and BS = Burnt Sugarcane.

Comparisons of chemical attributes and organic matter fractions

The correlation analyses showed different patterns among fertility properties and soil organic fractions (Table 4). There was a negative correlation between the values of pH and Al³⁺, Al³⁺ and Ca²⁺ + Mg²⁺, and FA-C and POM. The opposite was

observed for values of pH and Ca²⁺ + Mg²⁺, pH and assimilable P, assimilable P and Ca²⁺ + Mg²⁺, TOC and Ca²⁺ + Mg²⁺, HU-C and Ca²⁺ + Mg²⁺, and HA-C and Ca²⁺ + Mg²⁺ that were positively correlated. The values of TOC, HU-C, FA-C, HA-C, and MOM were positively correlated as well.

Table 4. Pearson correlation (r) between soil fertility properties and SOM fractions in the 0.0-0.1 m soil layer.

	MOM	pH	Ca ²⁺ + Mg ²⁺	Al ³⁺	P	K ⁺	TOC	HU-C	FA-C	HA-C
pH	-0.18 ^{ns}									
Ca ²⁺ + Mg ²⁺	0.34 ^{ns}	0.44 [*]								
Al ³⁺	-0.18 ^{ns}	-0.64 ^{**}	-0.42 [*]							
P	-0.21 ^{ns}	0.65 ^{**}	0.41 [*]	-0.20 ^{ns}						
K ⁺	-0.11 ^{ns}	0.24 ^{ns}	0.04 ^{ns}	-0.12 ^{ns}	0.22 ^{ns}					
TOC	0.99 ^{**}	-0.18 ^{ns}	0.40 [*]	-0.15 ^{ns}	-0.19 ^{ns}	-0.14 ^{ns}				
HU-C	0.93 ^{**}	-0.22 ^{ns}	0.37 [*]	-0.16 ^{ns}	-0.25 ^{ns}	-0.20 ^{ns}	0.94 ^{**}			
FA-C	0.63 ^{**}	-0.23 ^{ns}	0.23 ^{ns}	-0.11 ^{ns}	-0.05 ^{ns}	0.16 ^{ns}	0.65 ^{**}	0.52 ^{**}		
HA-C	0.77 ^{**}	-0.02 ^{ns}	0.48 ^{**}	-0.27 ^{ns}	0.09 ^{ns}	-0.19 ^{ns}	0.79 ^{**}	0.69 ^{**}	0.54 ^{**}	
POM	-0.19 ^{ns}	0.03 ^{ns}	0.33 ^{ns}	0.15 ^{ns}	0.14 ^{ns}	-0.11 ^{ns}	-0.02 ^{ns}	-0.01 ^{ns}	-0.47 [*]	0.01 ^{ns}

P = assimilable P; TOC = total organic carbon; HU-C = humin fraction carbon; FA-C = fulvic acid fraction carbon; HA-C = humic acid fraction carbon; POM = particulate organic matter; MOM = organic matter associated to the minerals fractions. *: p < 0.05, **: p < 0.01, ns: not significant, t-test.

Discussion

The MT treatment provided greater protection of the soil TOC compared with the CT, and this effect may have influenced the greater availability of nutrients such as Ca²⁺ and Mg²⁺, as well as leading to greater sum of bases and base saturation values. The process of immobilization of nutrients in soil organic pools in the MT treatment associated with the annual addition of residue after harvesting, plus the roots of previous cycle of sugarcane that are renewed in every cutting, may have favored the dynamic of potassium. This result is due to K⁺ dynamics, since this element is not incorporated into the carbon chains of soil organic matter but, rather, quickly returns to soil in a form readily available to plants, converting the residue into an important short-term reservoir of K⁺ (ROSOLEM et al., 2007). Thus, the potential for K⁺ leaching is decreased, which is even more important in sandy soils, where the texture favors high nutrient losses (ROSOLEM et al., 2010). The higher amount of available P below the topsoil under CT compared with MT is explained by incorporation of crop residues and phosphate fertilizers to a greater depth with the tillage (CALEGARI et al., 2013). This explanation was presented by Mendoza et al. (2000) studying in the same area and at the beginning of

this experiment evaluating burnt and unburned and CT original treatments.

A greater availability of P in areas where residues were removed (by burning) instead of retained on the soil, especially in the surface layer, was verified by Correia and Alleoni (2011), Thorburn et al. (2012) and Torres et al. (2013). The result was related to the formation of calcium phosphate, present in the ashes from the residue deposited on soil surface (BALL-COELHO et al., 1993). In systems where the residue is not burned, an increase in P available is not expected because the sugarcane residue has a high C:P ratio and there is a relatively low amount of this element.

Mendoza et al. (2000) also reported greater availability of Mg²⁺ and TOC in the unburned sugarcane plots. In Paraguaçu Paulista – SP, in a Dystrophic Red Latosol (Oxisol), Souza et al. (2012) reported higher values of pH, TOC, Ca²⁺, Mg²⁺, K⁺ and lower values of Al³⁺ and H+Al in the area with the unburned sugarcane compared to the burned cane and native forest. These results show the positive effect of maintaining the residues on the soil surface, and with adoption of minimum tillage there is potential for a positive effect on sugarcane management system.

The study showed a poor contribution of CT-BS management in terms of preserving and increasing SOM. Therefore, in areas of sugarcane production with sandy surface texture, as in the studied soils, the content of SOM gradually decreases and the practices of conventional tillage plus burning prior to harvest greatly further reduce the sustainability of this system.

In the same experimental site, Mendoza et al. (2000) observed that in the 0.0-0.05 m layer, the maintenance of the residue on soil surface increased the levels of HU-C and FA-C; this was also corroborated by Canellas et al. (2003) in areas with and without residue burning over a long period of time and with vinasse application. The MT management of sugarcane areas in the coastal tableland soils provides greater protection and/or increased C in humic substance fractions. In contrast, in conventional tillage systems, plowing and harrowing turn the soil and increase aeration, favoring the growth of microbial and soil fauna that participate in SOM decomposition (ROSSETTO et al., 2008), generally resulting in lower organic carbon content in the CT systems.

Some studies have shown that most of the C accumulated in minimal tillage and no-till systems, relative to CT, is stored in the mineral-associated fraction, emphasizing the importance of the organo-mineral interaction as a stabilization mechanism in these systems (CAMPOS et al., 2011; PINHEIRO et al., 2015). In contrast, soil organic C associated with sand fractions was the most sensitive C fraction responding to soil tillage systems in a short period of time in areas cultivated with sugarcane in Australia (THORBURN et al., 2012) and with a rotation of vegetables, including tomato, green pepper and beans, in Rio de Janeiro State, Brazil (PINHEIRO et al., 2015). The absence of a response for POM in this study may be related to the soil sampling period because the largest amount of residues is observed immediately after harvesting. Additionally, environmental conditions of the experimental area and the sandy soil texture favor

the rapid mineralization of the most labile OM fractions.

The influence of sugarcane residue management on organic matter was studied by Razafimbelo et al. (2006) in a clayey Oxisol from southern Brazil, and the results indicated that residue retention resulted in carbon enrichment mainly in the MOM fraction, whereas POC fractions were not enriched. These findings are completely contrary to those reported by Silva et al. (2006) in an *Argissolo Amarelo coeso*, a common soil in coastal tableland environment. The authors reported that 25 years of cultivation with soil tillage, using disking operations in the renovation of cane fields and burning sugarcane before harvesting, caused reduction in the carbon content of POM and MOM in the layer of 0-0.2 m. These negatives effects indicate the importance of residue retention and reduction of tillage for soil carbon storage, and reinforce the importance of fractions of the organic matter to assess soil management practices.

The correlation analysis indicated that the management system that provides the highest TOC also provides higher levels of C in the humic substance fractions and a greater potential to provide the nutrients Ca^{2+} , Mg^{2+} , K^+ , and assimilable P. This, in turn, increases pH and reduces levels of Al^{3+} in the soil. These results corroborate those obtained by Correia and Alleoni (2011), Loss et al. (2010) and Siqueira Neto et al. (2009). In sugarcane production, management systems that lead to an addition and/or preservation of SOM positively influence the maintenance of soil exchangeable bases and increased cation exchange capacity, thus benefiting the soil-plant system.

Conclusion

The results showed the importance of assessing the impact of soil tillage and residue management to ensure adequate sugarcane production systems. The minor soil disturbance in the MT treatment resulted in increased levels of $\text{Ca}^{2+} + \text{Mg}^{2+}$ by about 34% and TOC of 100%, in all soil layers; and for the K^+ more

than 5 times in the 0.1-0.2 m layer compared to the CT. The CT treatment associated with the burnt sugarcane management negatively influenced the TOC content, especially in the 0.1-0.2 and 0.2-0.4 m layers. Most of the C accumulated in the MT system, relative to the CT system, was in the humin fraction (HU-C) and in the mineral-associated fraction (MOM); which points to the importance of organo-mineral interaction as a stabilization mechanism that is ensured in the MT system. However, the residue management treatments showed no differences in the HU-C and in particle size fractions of SOM in the conditions of this study.

Acknowledgments

We acknowledge FAPERJ-Brazil for the scholarship, the distillery LASA and the Research Experimental Station-UFRRJ for technical support, and the CPGA-CS and FAPUR for financing the project.

References

- BALL-COELHO, B.; SALCEDO, I. H.; TIESSEN, H.; STEWART, J. W. B. Short- and long-term phosphorus dynamics in a fertilized Ultisol under sugarcane. *Soil Science Society of America Journal*, Madison, v. 57, p. 1027-1034, 1993. Available at: <<http://dx.doi.org/10.2136/sssaj1993.03615995005700040025x>>. Accessed at: 28 nov. 2014.
- BENAZZI, E. S.; BIANCHI, M. O.; CORREIA, M. E. F.; LIMA, E.; ZONTA, E. Impactos dos métodos de colheita da cana-de-açúcar sobre a macrofauna do solo em área de produção no Espírito Santo-Brasil. *Semina: Ciências Agrárias*, Londrina, v. 34, n. 6, p. 3425-3442, 2013. Disponível em: <<http://dx.doi.org/10.5433/1679-0359.2013v34n6Supl1p3425>>. Acesso em: 02 aug. 2016.
- BENITES, V. M.; MADARI, B.; MACHADO, P. L. O. A. *Extração e fracionamento quantitativo de substância húmicas do solo: um procedimento simplificado de baixo custo*. Rio de Janeiro: EMBRAPA Solos, 2003. 7 p. (Comunicado técnico, 16).
- BLAIR, N. Impact of cultivation and sugar-cane green trash management on carbon fractions and aggregate stability for a chromic luvisol in Queensland, Australia. *Soil and Tillage Research*, Amsterdam, v. 55, n. 3-4, p. 183-191, 2000. Available at: <[http://dx.doi.org/10.1016/S0167-1987\(00\)00113-6](http://dx.doi.org/10.1016/S0167-1987(00)00113-6)>. Accessed at: 28 nov. 2014.
- BLANCO-MOURE, N.; GRACIA, R.; BIELSA, A. C.; LOPEZ, M. V. Long-term no-tillage effects on particulate and mineral-associated soil organic matter under rainfed Mediterranean conditions. *Soil Use Manage*, Oxford, v. 29, n. 2, p. 250-259, 2013. Available at: <<http://dx.doi.org/10.1111/sum.12039>>. Accessed at: 13 dec. 2015.
- CALEGARI, A.; TIECHER, T.; HARGROVE, W. L.; RALISCH, R.; TESSIER, D.; TOURDONNET, S.; GUIMARÃES, M. F.; SANTOS, D. R. Long-term effect of different management systems and winter crops on soil acidity and vertical distribution of nutrients in a Brazilian Oxisol. *Soil and Tillage Research*, Amsterdam, v. 133, p. 32-39, 2013. Available at: <<http://dx.doi.org/10.1016/j.still.2013.05.009>>. Accessed at: 13 dec. 2015.
- CAMBARDELLA, C. A.; ELLIOTT, E. T. Particulate soil organic matter changes across a grassland cultivation sequence. *Soil Science Society of America Journal*, Madison, v. 56, n. 3, p. 777-783, 1992. Available at: <<http://dx.doi.org/10.2136/sssaj1992.03615995005600030017x>>. Accessed at: 22 oct. 2016.
- CAMPOS, B. H. C.; AMADO, T. J. C.; BAYER, C.; NICOLOSO, R. S.; CARNEIRO, T. J. Carbon stock and its compartments in a subtropical Oxisol under long-term tillage and crop rotation systems. *Revista Brasileira de Ciência do Solo*, Viçosa, MG, v. 35, n. 3, p. 805-817, 2011. Available at: <<http://dx.doi.org/10.1590/S0100-06832011000300016>>. Accessed at: 28 nov. 2014.
- CANELLAS, L. P.; VELLOSO, A. C. X.; MARCIANO, C. R.; RAMALHO, J. F. G. P.; RUMJANEK, V. M.; REZENDE, C. E.; SANTOS, G. A. Propriedades químicas de um Cambissolo cultivado com cana-de-açúcar, com preservação do palhico e adição de vinhaça por longo tempo. *Revista Brasileira de Ciência do Solo*, Viçosa, MG, v. 27, n. 5, p. 935-944, 2003. Disponível em: <<http://dx.doi.org/10.1590/S0100-06832003000500018>>. Acesso em: 9 sep. 2013.
- COMPANHIA NACIONAL DE ABASTECIMENTO – CONAB. Monitoring of the Brazilian harvest: sugarcane, third survey, December 2014 – National company of supply. Brasília: Superintendência de Marketing e Comunicação (Sumac) e Gerência de Eventos e Promoção Institucional (Gepin), 2014. Available at: <<http://www.conab.gov.br>>. Accessed at: 15 apr. 2016.
- CORRÊA, M. M.; KER, J. C.; BARRÓN, V.; TORRENT, J.; CURI, N.; TORRES, T. C. P. Caracterização física, química, mineralógica e micromorfológica de horizontes coesos e fragipãs de solos vermelhos e amarelos do ambiente Tabuleiros Costeiros. *Revista Brasileira de Ciência do Solo*, Viçosa, MG, v. 32, n. 1, p. 297-313,

2008. Disponível em: <<http://dx.doi.org/10.1590/S0100-06832008000100028>>. Acesso em: 13 dec. 2015.
- CORREIA, B. L.; ALLEONI, L. R. F. Conteúdo de carbono e atributos químicos de Latossolo sob cana-de-açúcar colhida com e sem queima. *Pesquisa Agropecuária Brasileira*, Brasília, v. 46, n. 8, p. 944-952, 2011. Disponível em: <<http://dx.doi.org/10.1590/S0100-204X2011000800022>>. Acesso em: 03 apr. 2016.
- EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA – EMBRAPA. Centro Nacional de Pesquisa de Solos. Manual de Métodos de Análises de Solos. Rio de Janeiro: EMBRAPA Solos, 1997. 212 p.
- GALDOS, M. V.; CERRI, C. C.; CERRI, C. E. P. Soil carbon stocks under burned and unburned sugarcane in Brazil. *Geoderma*, Amsterdam, v. 153, n. 3-4, p. 347-352, 2009. Available at: <<http://dx.doi.org/10.1016/j.geoderma.2009.08.025>>. Accessed at: 25 jan. 2016.
- GRAHAM, M. H.; HAYNES, R. J.; MEYER, J. H. Soil organic matter content and quality: effects of fertilizer applications, burning and trash retention on a long-term sugarcane experiment in South Africa. *Soil Biology and Biochemistry*, Oxford, v. 34, n. 1, p. 93-102, 2002. Available at: <[http://dx.doi.org/10.1016/S0038-0717\(01\)00160-2](http://dx.doi.org/10.1016/S0038-0717(01)00160-2)>. Accessed at: 05 apr. 2014.
- HOUX, J. H.; WIEBOLD, W. J.; FRITSCHI, F. B. Long-term tillage and crop rotation determines the mineral nutrient distribution of some elements in a Vertic Epiaqualf. *Soil and Tillage Research*, Amsterdam, v. 122, n. 1, p. 27-35, 2011. Available at: <<http://dx.doi.org/10.1016/j.still.2010.11.003>>. Accessed at: 23 mar. 2015.
- LOSS, A.; PEREIRA, M. G.; SCHULTZ, N.; ANJOS, L. H. C.; SILVA, E. M. R. Quantificação do carbono das substâncias húmicas em diferentes sistemas de uso do solo e épocas de avaliação. *Bragantia*, Campinas, v. 69, n. 4, p. 1-10, 2010. Disponível em: <<http://dx.doi.org/10.1590/S0006-87052010000400018>>. Acesso em: 9 sep. 2014.
- MENDOZA, H. N. S.; LIMA, E.; ANJOS, L. H. C.; SILVA, L. A.; CEDDIA, M. B.; ANTUNES, M. V. M. Propriedades químicas e biológicas de solo de tabuleiro cultivado com cana-de-açúcar com e sem queima da palhada. *Revista Brasileira de Ciência do Solo*, Viçosa, MG, v. 24, n. 1, p. 201-207, 2000.
- MONITORAMENTO DA CANA-DE-AÇÚCAR POR IMAGENS DE SATÉLITE – CANASAT. Monitoramento anual do cultivo da cana-de-açúcar nas seguintes classes: soca, expansão, em reforma (18 meses) e reformada (18 meses). São José dos Campos, SP: Instituto Nacional de Pesquisas Espaciais – INPE, 2014. Available at: <<http://www.dsr.inpe.br/laf/canasat/>>. Accessed at: 22 dec. 2014.
- OLIVEIRA, M. W. de; TIVELIN, P. C. O.; KINGSTON, G.; BARBOSA, M. H. P.; VITTI, A. C. Decomposition and reslease of nutrients from sugarcane trash in two agricultural environments in Brazil. In: *Proceedings of the Conference of Australian Society of Sugar Cane Technologists*, Queensland, v. 24 (ed. Hogarth DM), p. 290-296, 2002.
- PINHEIRO, E. F. M.; CAMPOS, D. V. B.; BALIEIRO, F. C.; ANJOS, L. H. C.; PEREIRA, M. G. Tillage systems effects on soil carbon stock and physical fractions of soil organic matter. *Agricultural Systems*, v. 132, p. 35-39, 2015. Available at: <<http://dx.doi.org/10.1016/j.agsy.2014.08.008>>. Accessed at: 25 jan. 2016.
- RAHMAN, M. H.; OKUBO, A.; SUGIYAMA, S.; MAYLAND, H. F. Physical, chemical and microbiological properties of an Andisol as related to land use and tillage practice. *Soil Tillage Research*, Amsterdam, v. 101, n. 1-2, p. 10-19, 2008. Available at: <<http://dx.doi.org/10.1016/j.still.2008.05.006>>. Accessed at: 17 feb. 2015.
- RAZAFIMBELO, T.; BARTHÈS, B.; LARRÉ-LARROUYA, M. C.; DE LUCA, E. F.; LAURENT, J. Y.; CERRI, C. C.; FELLER, C. Effect of sugarcane residue management (mulching versus burning) on organic matter in a clayey Oxisol from southern Brazil. *Agriculture, Ecosystems and Environment*, Amsterdam, v. 115, n. 1-4, p. 285-289, 2006. Available at: <<http://dx.doi.org/10.1016/j.agee.2005.12.014>>. Accessed at: 9 sep. 2014.
- ROBERTSON, F. A.; THORBURN, P. J. Management of sugarcane harvest residues: consequences for soil carbon and nitrogen. *Australian Journal of Soil Research*, Melbourne, v. 45, p. 13-23, 2007. Available at: <<http://dx.doi.org/10.1071/SR06080>>. Accessed at: 28 nov. 2014.
- ROSOLEM, C. A.; CALONEGO, J. C.; FOLONI, J. S. S.; GARCIA, R. A. Potássio lixiviado da palha de aveia-preta e milho após a dessecação química. *Pesquisa Agropecuária Brasileira*, Brasília, v. 42, n. 8, p. 1169-1175, 2007.
- ROSOLEM, C. A.; SGARIBOLDIA, T.; GARCIA, R. A.; CALONEGO, J. C. Potassium leaching as affected by soil texture and residual fertilization in tropical soils. *Communications in Soil Science and Plant Analysis*, Philadelphia, v. 41, n. 16, p. 1934-1943, 2010. Available at: <<http://dx.doi.org/10.1080/00103624.2010.495804>>. Accessed at: 03 apr. 2016.

- ROSSETTO, R.; CANTARELLA, H.; DIAS, F. L. F.; LANDELL, M. G. A.; VITTI, A. C. Manejo conservacionista e reciclagem de nutrientes em cana-de-açúcar tendo em vista a colheita mecânica. *Informações Agronômicas*, Piracicaba, n. 124, p. 8-13, 2008.
- SEGNINI, A.; CARVALHO, J. L. N.; BOLONHEZI, D.; MILORI, D. M. B. P.; SILVA, W. T. L.; SIMÕES, M. L.; CANTARELLA, H.; MARIA, I. C.; MARTIN-NETO, L. Carbon stock and humification index of organic matter affected by sugarcane straw and soil management. *Scientia Agricola*, Piracicaba, v. 70, n. 5, p. 321-326, 2013. Available at: <<http://dx.doi.org/10.1590/S0103-90162013000500006>>. Accessed at: 17 sep. 2014.
- SILVA, A. J. N.; CABEDA, M. S. V.; CARVALHO, F. G. Matéria orgânica e propriedades físicas de um Argissolo Amarelo Coeso sob sistemas de manejo com cana-de-açúcar. *Revista Brasileira de Engenharia Agrícola e Ambiental*, Campina Grande, v. 10, n. 3, p. 579-585, 2006. Disponível em: <<http://dx.doi.org/10.1590/S1415-43662006000300007>>. Acesso em: 13 dec. 2014.
- SIQUEIRA NETO, M.; PICCOLO, M. C.; SCOPEL, E.; COSTA JUNIOR, C.; CERRI, C. C.; BERNOUX, M. Carbono total e atributos químicos com diferentes usos do solo no Cerrado. *Acta Scientiarum Agronomy*, Maringá, v. 31, n. 4, p. 709-717, 2009. Disponível em: <<http://dx.doi.org/10.4025/actasciagron.v31i4.792>>. Acesso em: 25 jan. 2015.
- SOUZA, R. A.; TELLES, T. S.; MACHADO, W.; HUNGRIA, M.; TAVARES FILHO, J.; GUIMARÃES, M. F. Effects of sugarcane harvesting with burning on the chemical and microbiological properties of the soil. *Agriculture, Ecosystems and Environment*, Amsterdam, v. 155, p. 1-6, 2012. Available at: <<http://dx.doi.org/10.1016/j.agee.2012.03.012>>. Accessed at: 9 sept. 2014.
- SWIFT, R. S. Organic matter characterization. In: SPARKS, D. L. (Ed.). *Methods of soil analysis*. Part 3. Madison: America Society of Agronomy, 1996. p. 1011-1020.
- THORBURN, P. J.; MEIER, E. A.; COLLINS, K.; ROBERTSON, F. A. Changes in soil carbon sequestration, fractionation and soil fertility in response to sugar cane residue retention are site-specific. *Soil and Tillage Research*, Amsterdam, v. 120, p. 99-111, 2012. Available at: <<http://dx.doi.org/10.1016/j.still.2011.11.009>>. Accessed at: 9 sep. 2014.
- TORRES, J. L. R.; PEREIRA, M. G.; CUNHA, M. de A.; MARTINS, M. E.; VIEIRA, D. M. da S. Atributos físicos, químicos do solo e biomassa em sistemas de colheita de cana-de-açúcar. *Revista Brasileira de Ciências Agrárias*, Recife, v. 56, n. 4, p. 311-318, 2013.
- YAGI, R.; FERREIRA, M. E.; CRUZ, M. C. P.; BARBOSA, J. C.; ARAÚJO, L. A. N. Soil organic matter as a function of nitrogen fertilization in crop successions. *Scientia Agricola*, Piracicaba, v. 62, n. 4, p. 374-380, 2005. Available at: <<http://dx.doi.org/10.1590/S0103-90162005000400011>>. Accessed at: 03 apr. 2016.
- YEOMANS, J. C.; BREMNER, J. M. A rapid and precise method for routine determination of organic carbon in soil. *Communications in Soil Science and Plant Analysis*, Philadelphia, v. 19, n. 13, p. 1467-1476, 1998. Available at: <<http://dx.doi.org/10.1080/00103628809368027>>. Accessed at: 05 mar. 2012.