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SOIL AND PLANT NUTRITION - Article

Soil organic matter fractions affected by N-fertilizer in a green cane management in Brazilian Coastal Tableland

Shirlei Almeida Assunção*, Ana Paula Pessim Oliveira, Lúcia Helena Cunha dos Anjos, Marcos Gervasio Pereira, Eduardo Lima

Universidade Federal Rural do Rio de Janeiro - Departamento de Solos - Seropédica (RJ), Brazil.

ABSTRACT: The recent approach of eliminating the use of fire for sugarcane harvesting (green cane) resulted in managing the crop on a trash-blanketed soil, which changed the content and dynamic of carbon and the nitrogen requirement. These alterations are relevant due to economic and environmental aspects of sugarcane production systems. This study aimed to evaluate changes in total organic carbon (TOC), total nitrogen (TN) and soil organic matter fractions with the application of N-fertilizer on the residues of green cane. The experiment was with sugarcane at the fourth ratoon in Linhares, Espírito Santo State, Brazil. The soil is a Xanthic Dystrudults, originated from Barreiras Group sediments in the coastal tableland region. The treatments were set in a completely randomized blocks experimental design and consisted of N (as ammonium sulphate) dosages varying from 80 to 160 kg N.ha^{-1} and the control. The application of increasing N doses resulted in accumulation of TOC and carbon in the humic, granulometric and oxidizable fractions of soil organic matter (SOM). It was obtained a model adjustment for quadratic regression for TOC, NT and SOM fractions. The doses between 80 and 100 kg N.ha^{-1} were the most favorable to accumulate carbon and the SOM fractions. N doses higher than 100 kg N.ha^{-1} favored SOM mineralization. The SOM fractions were responsive to application of N-fertilizer on harvesting residues of the green cane management area.

Key words: soil management, *Saccharum officinarum*, sugarcane residues.

*Corresponding author: shirleiaassuncao@gmail.com

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INTRODUCTION

Studies in Brazil and different parts of the world highlight that in the green sugarcane cropping system, with crop residues accumulating above the ground, the N fertilizer requirements are different from those of systems with crop burning at harvest. (Graham et al. 2002; Thorburn et al. 2012; Oliveira et al. 2015). The main reason for changes in nitrogen requirements (N) is associated with the large volume of crop residues with high C:N ratio. It is reported that 12 to 20 Mg·ha^{-1} of straw (value based on the dry matter) are produced every year, forming a straw blanket on the soil during most of the crop cycle regrowth. Thus, when nitrogen fertilizer is applied, the soil organic matter (SOM) immobilization route is favored, due to the high amount of carbon structures resistant to decomposition (Thorburn et al. 2011; Oliveira et al. 2014). However, with addition of N-fertilizers in appropriate rates, the microbiological activity increases due to changes in the C:N ratio and lignin:N ratio as well as on microbial interactions, hence this reflects directly in the SOM decomposition (Graham et al. 2002; Potrich et al. 2014).

SOM is a key component of the soil quality, since it is the main cementing agent of soil particles, contributes for cation exchange capacity and water retention, and increases soil porosity, among other benefits (Santos et al. 2012; Yang et al. 2012). Some authors claim that effect of changes in the sugarcane residues management and in nitrogen fertilization on the SOM, even in a short period of time, can be identified by analyzing changes in compartments or fractions of SOM or organic carbon, which are more noticeable than total organic carbon (TOC) (Graham et al. 2002; Potrich et al. 2014; Thorburn et al. 2012).

Some techniques commonly used (Yeomans and Bremner 1988; Chan et al. 2001; Benites et al. 2003) to study the influence of soil management in SOM are: chemical fractionation, which separates the organic material into humic and fulvic acids, and humin; granulometric fractionation according to particle size, separating the sand size fractions or particulate organic carbon (> 53 µm) and carbon in the organic matter associated with silt (2 – 53 µm) and clay (0 – 2 µm) sizes; and oxidizable fractions of organic carbon, identified as F1, F2, F3 and F4, corresponding respectively to decreasing oxidation degrees at different sulfuric acid concentrations.

The labile fraction and the most stable fractions are equally important components in evaluation of SOM quality, which influences soil attributes and may increase the crop productivity. The N mineralizable, for example, can contribute significantly to provide the crop N requirements, and to increase microbial activity and organic matter fractions, which are directly associated to soil aggregation (Graham et al. 2002; Santos et al. 2012).

Studies on this subject are lacking in soils from the Brazilian coastal tableland region, which typically have low fertility and may present cohesive horizons below the arable layer that limit the root development. The clay mineralogy of these soils is kaolinitic, and the cation exchange capacity is highly dependent on soil organic carbon content (Corrêa et al. 2008). Sugarcane is the dominant crop cultivated in the coastal tablelands soils due to favorable climatic conditions and the plain to gently undulating topography that offers good conditions for soil tillage.

The objective of this study was to evaluate changes in total organic carbon (TOC), total nitrogen (TN) and organic matter fractions in a soil with application of different dosages of N-fertilizer on residues of green cane in an area located in the coastal tabeland region of Linhares, Espírito Santo State, Brazil. The hypothesis is that the amount of N-fertilizer applied on sugarcane straw deposited after mechanized harvesting, when the green cane system is adopted, will influence the content and dynamic of total carbon and the different fractions of soil organic matter.

MATERIAL AND METHODS

The study was carried out in the production area of LASA distillery, located in Linhares, Espírito Santo State, Southeast of Brazil (19°18'S and 40°19'W). The physiographic region is known as lowlands of the Doce River, and the topography is of a gently sloping. The soils in this area are originated from coastal tableland weathered sediments of the Barreiras Group, Tertiary period. The soil was classified as Xhantic Dystrudults and has sandy over loamy texture class. The soil chemical and physical characteristics are presented in Table 1. The experiment area (2,240 hectares) has been under commercial cultivation of green cane since 2007 and, before that, it was under coverage of pasture with low intensity management. The experimental plots were set up in the year of 2009, when the sugarcane field

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Table 1. Chemical and physical characteristics of soil samples taken from sugarcane experimental area at LASA Sugar and Ethanol Plant, Linhares, Espírito Santo, Brazil.

Soil depth (m)	Chemical analyses								
	H+Al	Al	Ca	Mg	Valor S	K^+	P (Mehlich)	V (%)	pH (water)
	$cmol_c/dm^{-3}$					$(mg{\cdot}dm^{-3})$			
0 – 0.05	10.5	0.7	0.6	0.20	0.86	22.2	4.9	7.6	4.7
0.05 – 0.10	7.4	0.8	0.4	0.12	0.54	10.2	2.9	7.1	5.1
0.10 – 0.20	6.0	0.7	0.4	0.04	0.53	6.1	2.7	8.6	5.1

Soil depth (m)	Physical analyses				
	Bulk density $(Mg{\cdot}m^{-3})$	Sand	Silt	Clay	Soil texture class
		$g{\cdot}kg^{-1}$			
0 – 0.05	1.57	84.4	9.2	6.4	Loamy sandy
0.05 – 0.10	1.57	83.4	8.9	7.8	Loamy sandy
0.10 – 0.20	1.57	81.8	8.9	9.3	Loamy sandy
0.20 – 0.40	1.55	83.7	7.4	10.2	Loamy sandy
0.40 – 0.60	1.41	81.0	7.0	13.4	Sandy loam

was renewed and the variety RB 918639 was planted. The study was performed during the fourth cane ratoon cycle, from November 2013 to September 2014.

After mechanical harvesting, the plots were delimited and five treatments, composed of the control (without N) and increasing N rates (80, 100, 120 and 160 kg $N{\cdot}ha^{-1}$) in the form of ammonium sulphate ($(NH_4)_2SO_4$), were arranged in completely randomized blocks with four replicates. The plot size was of 70 m^2 with five plant rows of 10 m and a length spaced of 1.4 m. Each N dosage was manually applied on the straw blanket of the respective plots at a 0.2 m distance from the crop line. Phosphorus was added only at the moment of planting (100 kg $P_2O_5{\cdot}ha^{-1}$ as single superphosphate); K and micronutrients were applied at the rates of 100 kg $K_2O{\cdot}ha^{-1}$ as KCl and 40 $kg{\cdot}ha^{-1}$ of FTE BR12 (9% Zn, 1.8% B, 0.8% Cu, 2% Mn, 3.5% Fe, 0.1% Mo), respectively. There was no liming. In September 2014 the soil was sampled transversely to the planting line at 0 – 0.05 m, 0.05 – 0.1 m, and 0.1 – 0.2 m depths. Two samples were taken at each depth, forming a composite sample with four replicates for each treatment. The samples were identified, conditioned in plastic bags and taken to laboratory, where they were air dried and sieved (2 mm mesh).

The TOC was quantified according to the method of Yeomans and Bremner (1988). The method of differential solubility, as established by the International Humic Substances Society and adapted by Benites et al. (2003), was used for extraction and fractionation of humic substances. It relies on solubility in alkaline and acid and subsequent determination of carbon of each fraction, namely fulvic acid fraction (C-FAF), humic acid fraction (C-HAF) and humin fraction (C-HU).

The SOM granulometric fractions were quantified after mixing 20 g of soil in 60 ml of sodium hexametaphosphate solution (5 $g{\cdot}L^{-1}$) and separating the sand from the silt and clay size fractions using a 53 µm sieve (Cambardella and Elliot 1992). The material retained in the sieve, which consisted of particulate organic carbon (POC) associated with the sand fraction, was dried at 60 °C and ground in a porcelain mortar. The organic carbon was analyzed according to the method of Yeomans and Bremner (1988) and quantified in relation to its mass. The material that passed through the 53 µm sieve, which consisted of organic carbon associated to the minerals fractions (OCam) in the silt and clay fractions, was calculated as the difference between the TOC and the POC.

Fractionation of C by degrees of oxidation was performed according to methods adapted by Chan et al. (2001). Four fractions with decreasing degrees of oxidation were obtained: a) Fraction 1 (F1) – C oxidized by $K_2Cr_2O_7$ in an acid medium of 3mol·L^{-1} H2SO4; b) Fraction 2 (F2) – C difference oxidized by $K_2Cr_2O_7$ in an acid medium of 6 and 3 mol·L^{-1} H_2SO_4; c) Fraction 3 (F3) – C difference oxidized by $K_2Cr_2O_7$ in an acid medium of 9 and 6 mol·L^{-1} H_2SO_4; and d) Fraction 4 (F4) – C difference oxidized by $K_2Cr_2O_7$ in an acid medium of 12 and 9 mol·$L^{-1}H_2SO_4$ and the TOC.

The resulting data were submitted to normality (Shapiro-Wilk) and homocedasticity of variances (Bartlett) tests. Subsequently, the results were analyzed for variance using

F-test, and when there was a significant effect a quadratic regression was used. The software used for the statistical analyzes was the R 3.3.0. A Multivariate Factorial Analysis (AMF) was also performed to describe the covariance relationships between the variables (Bouruche and Saporta 1980), thus facilitating the observation of possible similarities and dissimilarities among the variables. The AMF can be considered an extension of the Principal Components Analysis, but the AMF-based approach is more elaborate and is performed from a mathematical model, presented in Eq. 1:

$$V(X - \mu) = LF + \text{€} \qquad (1)$$

where: L = matrix of loading factorials; F = random vector containing m factors; and € = vector of random errors.

RESULTS AND DISCUSSION

The analyzes of TOC, TN, and the humic, granulometric and oxidizable fractions of the SOM were performed in the soil layers of 0 – 0.05 m, 0.05 – 0.10 m and 0.10 – 0.20 m. However, there was adjustment of the model for quadratic regression only in the 0 – 0.05 m layer. Thus, the equations of the TOC and TN variables were presented for all layers, and for the fractionation of the SOM the equations refer to the 0 – 0.05 m layer. One of the reasons for this lack of adjustment to the model may be weather conditions at the study site, which presents high precipitation rates and elevated temperatures (Figure 1) concomitant with the sandy texture of the upper layers, contributing to higher soil losses. These factors lead to losses of SOM due to increasing mineralization and immobilization of N.

There was a significant quadratic response to N doses for the TOC variable in the 0 – 0.05 m layer (Figure 2a) with an increase in the amount of TOC between 80 and 100 kg of N. The amount of TOC decreased with the increase of nitrogen fertilization for the dosage of 120 kg of N and higher. The high concentration of N may have intensified soil biological activity and, when combined with the area weather conditions, influenced the SOM decomposition rate, increasing its mineralization. The cultivation of plants with high C:N ratio may lead to stabilization of C in the soils. However, for this to occur, nitrogen availability at adequate doses is required (Diekow et al. 2005), since very high doses favor mineralization processes with consequent loss of C in the system.

There was a significant quadratic response to N rates for the TN variable only in the 0 – 0.05 m layer (Figure 2b). In the months subsequent to sugarcane fertilization, there was

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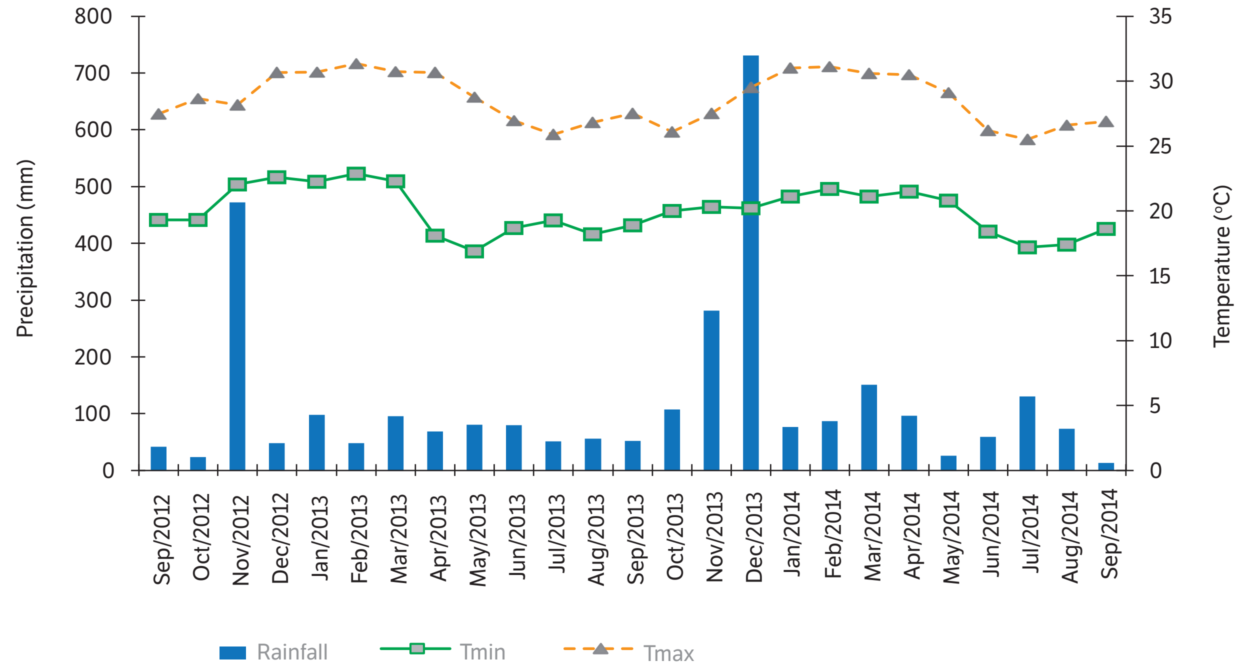
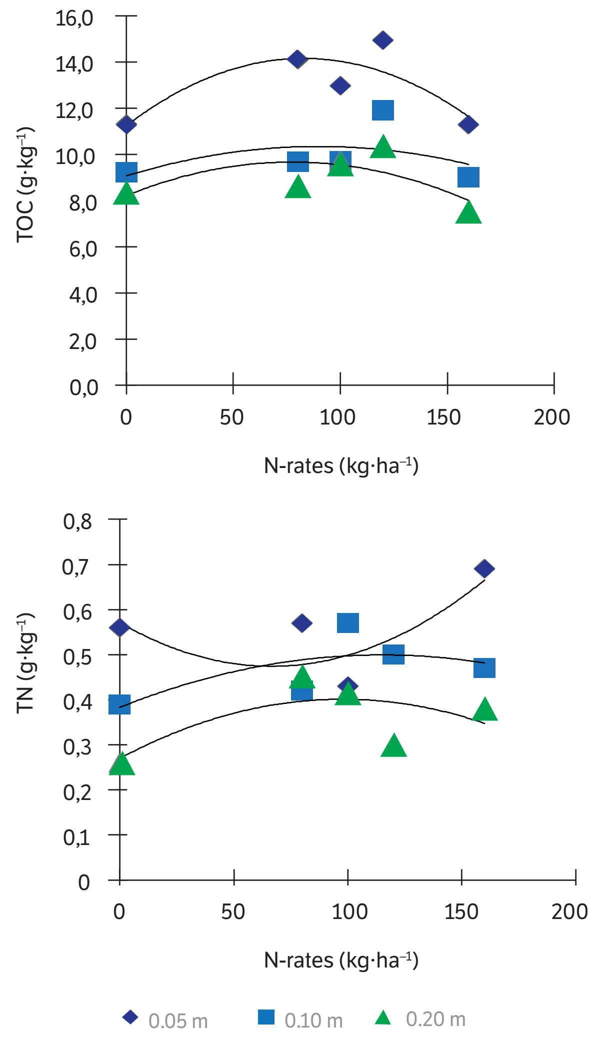
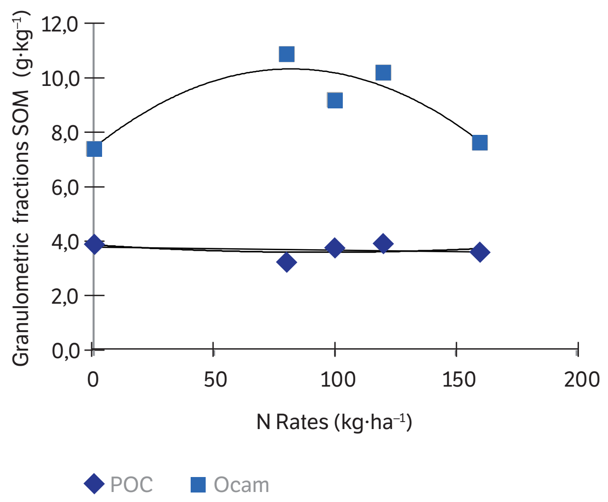


Figure 1. Maximum (Tmax) and minimum (Tmin) average values for temperature and rainfall, from September 2012 to September 2014. Source: LASA Weather Station (2015).



$Y^{COT}(0.05\ m) = 0.00042x^2 + 0.0703x + 11.236,\ R^2 = 0.6676,\ p < 0.001^*;$
$Y^{COT}(0.10m) = 0.0002x^2 + 0.0284x + 9.0596,\ R^2 = 0{,}2309,\ p = 0.1276^{NS};$
$Y^{COT}(0.20m) = 0.0002x^2 + 0.0377x + 8.2019,\ R^2 = 0.4821,\ p = 0{,}1276^{NS};$
$Y^{NT}(0.05m) = 2E{-}05x^2 - 0.0029x + 0{,}571,\ R^2 = 0.5398,\ p = 0.00053^*;$
$Y^{NT}(0.10m) = -9E{-}06x^2 + 0.002x + 0.3831,\ R^2 = 0.4854,\ p = 0.8978^{NS};$
$Y^{NT}(0.20m) = -3E{-}06\ x^2 - 0.0001x + 0.4624,\ R^2 = 0{,}486,\ p = 0.8790^{NS}.$

Figure 2. (a) total organic carbon (TOC) and (b) total nitrogen (TN) in the soil as a response to applied N-ammonium sulfate rates for green cane managed with straw retention at different soil depths.



$Y^{Ocam} = -0.0004x^2 + 0.0711x + 7{,}4221,\ R^2 = 0{,}8146,\ p < 0.001;$
$Y^{POC} = 3E{-}05x^2 - 0.006 + 3.8695,\ R^2 = 0.1826,\ p = 0.95^{NS}.$

Figure 3. Granulometric fractions of the SOM as a function of N-ammonium sulfate rate in green cane with straw retention at depths of 0 – 0.05 m. POC: particulate organic C; OCam: organic C associated to minerals.

a gradual increase of precipitation, exceeding 700 mm in less than 3 months (September to December of 2013) (Figure 1). The intense rain and the sandy texture of the surface soil layer contributed to the high losses of N in the system, thus resulting in the lack of model adjustment in the other layers.

The SOM carbon contents in the fulvic and humic acid fractions did not show significant response to the N rates, only the humin fraction was sensitive to N rates (Figure 3). These results corroborate other studies of SOM chemical fractionation in tropical environments (Mendoza et al. 2000; Canellas and Santos 2005; Rossi et al. 2011). The C-HU fraction has higher stability due to large amounts of functional groups that bind to soil minerals and, being more stable, it is less sensitive to changes in soil management (Canellas and Santos 2005). Due to the high stability of C-HU, the C increase in this fraction can be attributed to the previous land use, pasture or original Atlantic Forest, since the C-HU fraction amount in the soil is a product of various uses and coverings.

In studies with residues of rice plants using ^{13}C and ^{15}N marks, Moran et al. (2005) observed that mineral nitrogen addition increased the decomposition rate of the residues and contributed to the transference of C to the humin fraction with a positive effect on the SOM formation. They concluded that the N added to the soil was incorporated into the C structures and contributed to C increasing in the humin fraction.

The results of granulometric fractionation showed that the OCam fraction presented higher amount of C in relation to the POC fraction (Figure 4). The OCam fraction presented a significant model adjustment for different N doses. This result can be justified by a greatest interaction of the OCam fraction with soil minerals, resulting in a

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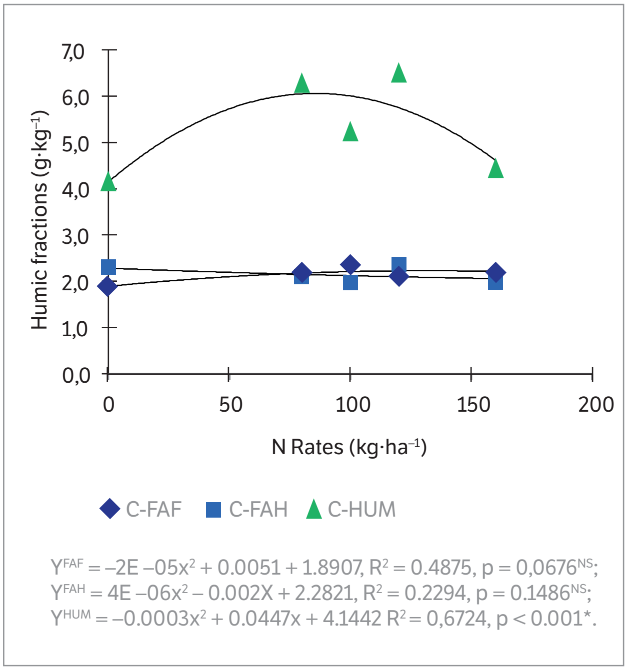

Figure 4. Carbon in humic fractions of SOM as a function of N-ammonium sulfate rate in green cane with straw retention at depths of 0 – 0.05 m. C-FAF: C in fulvic acid fraction; C-HAF: C in humic acid fraction; C-HU: C in humic fraction.

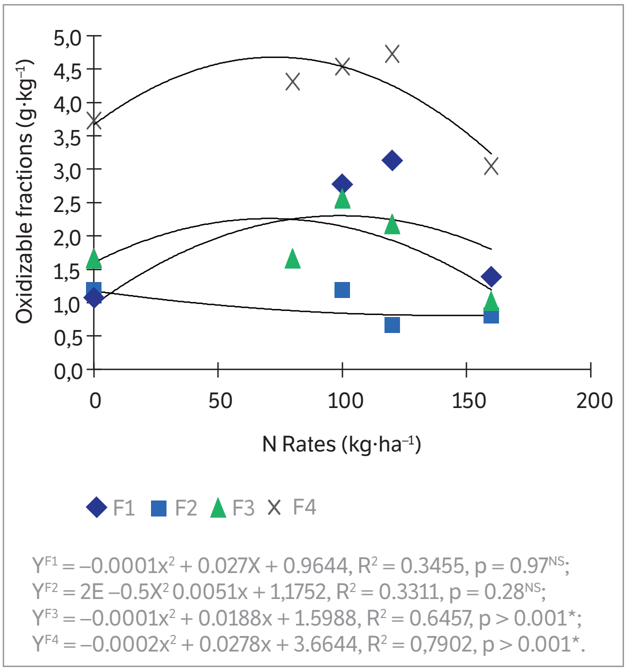

Figure 5. Carbon of the oxidizable fractions in the SOM assessed as a function of N-ammonium sulfate rate in green cane with straw retention at depths of 0 – 0.05 m. F1: fraction 1; F2: fraction 2; F3: fraction 3; and F4: fraction 4.

higher recalcitrance of this fraction and consequently lesser transformation. This favored the accumulation in the soil when quantities of nitrogen fertilizer between 80 and 100 kg of N·ha^{-1} were applied. According to Bayer et al. (2004), the OCam fraction is more stable and has a longer cycle than the POC fraction, so that it is unlikely to change over a short time.

There was no significant response between N rates for the POC (Figure 4). It is assumed that the POC greatest lability and susceptibility to changes according to soil management (Bayer et al. 2004), associated with weather conditions and soil texture, favored SOM mineralization and promoted C losses. According to Grandy and Neff (2008), in sandy texture soils the recalcitrance of the vegetal residue added to the soil seems to define the time of C permanence in the fraction POC. Therefore, it can be inferred that in the experimental site the residues of greater recalcitrance (OCam) are accumulated preferentially upon the more labile fraction (POC).

Among the TOC oxidizable fractions, there was a significant response only to fractions F3 and F4 (Figure 5), which have high recalcitrance and, therefore, high resistance to degradation. According to Macedo et al. (2008), the more recalcitrant organic compounds are decomposed by soil biota more slowly and, over time, this C is gradually incorporated into the soil. Studies with SOM fractionation indicate that the highest C content in the oxidizable fractions tends to be found in areas with higher input of organic matter from crop residues (Chan et al. 2001; Guareschi et al. 2013).

Comparison of C amounts in the SOM fractions obtained by physical fractionation (OCam), chemical (C-HU, C-FAF and C-HAF) and oxidizable fractions (F1, F2, F3 and F4), showed C accumulation in the most stable fractions as a function of nitrogen fertilization in the sugarcane straw. The N range that lead to most C accumulation was between 80 and 100 kg of N·ha^{-1}, for the conditions of this study. On the other hand, high amounts of N fertilizers, above 100 kg·ha^{-1}, are not recommended, since the excess of N may intensify SOM mineralization.

The factorial analysis with the choice of components by the Maximum Likelihood method (Table 2) showed that among the 11 factors (soil attributes), three explained approximately 75% of the soil attributes variability ($p = 2.31e^{-34}$). The factorial analysis allowed the selection of the variables that contributed the most to the results variability according to different N doses, namely: OCD = 0.998; OCam = 0.997; C-HU = 0.995 and TN = 0.971

Table 2. Factor analysis by Maximum Likelihood for soil attributes assessed as a function of N-ammonium sulfate rate in green cane with trash retention at depths of 0 – 0.05 m.

Importance of components[1]	Factor^1	Factor^2	Factor^3
SS loadings	3.403	2.871	1.979
Proportion Variance	0.309	0.261	0.180
Cumulative Variance	0.309	0.570	0.750
Soil attributes[2]	**Attributes variance**	**Error variance**	**Total variance**
TOC	0.998	0.002	1
POC	0.335	0.665	1
Ocam	0.997	0.003	1
NT	0.971	0.029	1
C-FAF	0.173	0.827	1
C-FAH	0.471	0.529	1
C-HUM	0.995	0.005	1
F1	0.718	0.282	1
F2	0.400	0.600	1
F3	0.779	0.221	1
F4	0.755	0.245	1

[1] Test of the hypothesis that 3 factors are sufficient. The chi square statistic is 226.42 on 25 degrees of freedom. The p-value is $2.31e^{-34}$. Ss loadings = variance explained by the factors; [2] TOC: Total organic carbon; TN: Total nitrogen; POC: particulate organic C; OCam: organic C associated to minerals; C-FAF: C in fulvic acid fraction; C-HAF: C in humic acid fraction; C-HU: C in humic fraction; F1: fraction 1; F2: fraction 2; F3; fraction 3 and F4: fraction 4.

(Table 2), all values near 100%. It is also possible to observe that the variance values attributed to the error of TOC, POC, OCam, C-HU and TN variables were very small, thus showing consistency in the results. This corroborates with the regression analysis, in which the variables listed above showed adjustment in the polynomial regression model.

CONCLUSION

The application of N-fertilizer in the sugarcane harvesting residues increased the content of TOC, TN, and chemical, physical and oxidizable fractions of organic matter for the 0 – 0.05 m soil layer.

The doses between 80 and 100 kg N·ha^{-1} were the most adequate to accumulate C and the SOM fractions. Doses above 100 kg N·ha^{-1} favored SOM mineralization, and the excess of N might have unbalanced the processes of decomposition and immobilization of SOM.

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ORCID IDs

S. A. Assunção
https://orcid.org/0000-0002-8947-4143
A. P. P. Oliveira
https://orcid.org/0000-0001-6571-8986
L. H. C. dos Anjos
https://orcid.org/0000-0003-0063-3521
M. G. P.
https://orcid.org/0000-0002-1402-3612
E. L.
https://orcid.org/0000-0002-9278-5831

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