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Carbon and nitrogen stocks in the soil and humic substances of agricultural crops in the semi-arid region[1]

Estoques de carbono e nitrogênio no solo e substâncias húmicas de cultivos agrícolas no semiárido

Rodinei Facco Pegoraro[2]*, Cristiano Gonçalves Moreira[3], Daniel Gonçalves Dias[4] and Thiago Correa Silveira[4]

ABSTRACT - The implementation of conservationist systems of cultivation, with less soil turning and a greater deposition of plant residue, has increased the stocks of C and N in soil and humic substances, but may reduce the quality of the organic matter (SOM). The aim of this study was to evaluate the storage of carbon and nitrogen in plant residue, humic substances and soil at three depths (0-0.2, 0.2-0.4 and 0.4-0.6 m) and under five systems of cultivation: an old banana plantation (14 years cultivation), renovated banana plantation (renewed 1.5 years earlier), sugarcane plantation (two years cultivation), pasture (three-year-old Colonial grass), *crotalaria juncea* (cultivated yearly for five years) and native forest, as a reference of a natural semi-arid environment. The dry weight of the plant residue deposited on the soil was determined, together with the levels and stocks of total carbon (C) and total nitrogen (TN), the stocks of C and N in the humic substances (fulvic acid, humic acid and humin fractions), and the C/N and C-HF/(C-FAF+C-FAH) ratios. The greatest levels of C were seen in the plant residue from the renewed banana plantation, pasture and *crotalaria*, but the deposition of dry matter and the stocks of C and TN were higher in the plant residue of the native forest. In the soil, the largest stocks of C and TN were found in the surface layers (0-0.2 and 0.2-0.4 m). The stock of C and TN, and of C in the humic fractions of the SOM did not differ between the majority of the cropping systems or the native forest, indicating the maintenance of C and N in the cultivated soils compared to the native vegetation. Cropping systems that include banana, sugarcane and *crotalaria* increase the C stock in the humin fraction and the degree of humification of the SOM at most of the soil depths under evaluation.

Key words: Vegetable residue. *Crotalaria*. Banana plantation. Sugar cane.

RESUMO - A adoção de sistemas conservacionistas de cultivo, com menor revolvimento do solo e maior deposição de resíduos vegetais têm aumentado o estoque de C, N no solo e substâncias húmicas, mas podem reduzir a qualidade da matéria orgânica (MOS). O estudo objetivou avaliar a estocagem de carbono e nitrogênio nos resíduos vegetais, substâncias húmicas e solo, em três profundidades (0-0,2; 0,2-0,4 e 0,4-0,6 m) e cinco sistemas de cultivo: bananal velho (14 anos de cultivo), bananal renovado (renovado há 1,5 anos), cana-de-açúcar (dois anos de cultivo), pastagem (capim colonião há três anos), crotalária juncea (cultivo anual há cinco anos) e a mata nativa como referência de ambiente natural do semiárido. Determinou-se a massa de matéria seca de resíduos vegetais depositada no solo, os teores e estoques de carbono total (C), nitrogênio total (NT), o estoque de C e N nas substâncias húmicas (frações ácido fúlvico, ácido húmico e humina) e as relações C/N e C-FH/(C-FAF+C-FAH). Os maiores teores de C foram observados nos resíduos vegetais de bananal renovado, pastagem e crotalária, mas a deposição de matéria seca e estoques de C e NT foram maiores nos resíduos vegetais da mata nativa. No solo, os maiores estoques de C e NT foram obtidos nas camadas superficiais (0-0,2 e 0,2-0,4 m). O estoque de C, NT e de C nas frações das substâncias húmicas da MOS não diferiu entre a maioria dos sistemas de cultivo e a mata nativa, indicando a manutenção do C e N nos solos cultivados em comparação à condição nativa. Os sistemas de cultivo com Bananal, cana-de-açúcar e crotalária aumentam o estoque de C na fração humina e o grau de humificação da MOS, na maioria das profundidades de solo avaliadas.

Palavras-chave: Resíduos vegetais. Crotalária. Bananal. Cana-de-açúcar.

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*Author for correspondence
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[1]Pesquisa financiada pelo CNPq e FAPEMIG
[2]Instituto de Ciências Agrárias, Universidade Federal de Minas Gerais, Avenida Universitária, 1.000, Bairro Universitário. Montes Claros-MG, Brasil, 39.404-547. rodinei_pegoraro@yahoo.com.br
[3]Departamento de Ciência do Solo, Universidade Federal de Lavras, Lavras-MG, Brasil, moreiracristianog@gmail.com
[4]Departamento de Ciências Agrárias, Universidade Estadual de Montes Claros, Janaúba-MG, Brasil, danielgon_d@hotmail.com, thiagocorrea.cm@hotmail.com

INTRODUCTION

Agricultural crops located in semi-arid regions of Brazil have presented difficulties in maintaining or increasing stocks of soil organic carbon. The productive capacity of agricultural systems, the original vegetation, soil texture, soil type and management, and the climate (CARVALHO *et al*., 2009; COSTA *et al*., 2009; MAIA *et al*., 2009; MODA *et al*., 2014 PEGORARO *et al*., 2014), are the main factors controlling the size and speed of changes in carbon stocks in the SOM (CARDOSO *et al*., 2010).

Intensive soil turning causes a 30% to 44% decrease in the C and N content of soils cultivated over long periods (SÁ *et al*., 2015; SCHWARTZ *et al*., 2015). Reducing cultivation intensity by planting tropical fruits, direct planting and increasing the deposition of plant residue may in turn increase the stocks of carbon and nitrogen in semi-arid soils (OLIVEIRA *et al*., 2013; PRASAD *et al*., 2016; PRINGLE *et al*., 2014; SALES *et al*., 2017). However, Barbera *et al*. (2012) reported the lowest, or no, difference in the storage of C and TN in the soil (0-15 cm layer) after 19 years of direct planting compared to a conventional system, in a semi-arid region of Italy. Those authors attributed this result to the lower susceptibility of the SOM to degradation, due to the recalcitrance of the plant residue (wheat) and the presence of soils with a high clay content (47.1 dag kg^{-1}), which affords the SOM greater physical protection.

The use of plant species that are more resistant to decomposition plays an important role in the storage of C and N in the soils of regions with a hot climate, where the degradation rate of straw is fast (CAETANO *et al*., 2013), possibly by increasing C storage in the humic substances of the SOM. As a result, the deposition of plant residue with a high C/N ratio, lignin and other recalcitrant compounds, alters the storage of C and N in the soil and humic fractions. Silva *et al*. (2016) found that the application of organic compost with different proportions of sheep manure and sugarcane, coconut, elephant grass, castor bean and achiote residue when growing mango in the semi-arid region of the State of Pernambuco, increased the stock of C in humic substances, especially in the humin fraction, indicating greater stability of the organic matter.

Greater C storage in the more recalcitrant fractions of SOM, such as the humic substances, contributes to an increase in the mean residence time of C in the soil (STEVENSON, 1994), which might result in greater storage of the element in the ecosystem (PEGORARO *et al*., 2011) and delay the emission of C-CO_2 into the atmosphere. Such a condition would be paramount to the sustainability of cultivated soil in semi-arid regions, due to the natural difficulty of producing and maintaining plant residue on the soil surface.

Studies related to changes in the storage of C and N in the soil and in the humic fractions of organic matter from annual crops and perennial irrigated fruit in the semi-arid region of the State of Minas Gerais are considered scarce. The aim of this study therefore, was to evaluate the storage of C and N in the soil and SOM fractions submitted to different crops and types of plant residue in the north of the State of Minas Gerais, Brazil.

MATERIAL AND METHODS

The study was carried out under field conditions, in different agricultural areas located in the District of Janaúba, Minas Gerais, located at 15°47’18” S and 43°18’18” W, at an altitude of 515 meters. According to the Köppen classification, the climate is type Aw, characterised as semi-arid. The mean annual rainfall is 740 mm, of which 85% occurs between November and March (INMET, 2014).

Based on the history of land use, agricultural areas were selected in the vicinity of the native vegetation; characterised as deciduous dry tropical forest of variable size, the trees have a height of less than 25 m and floristic composition common to the caatinga, cerrado and humid regions of the southeast (BRAZIL, 1982). Six different production systems were selected for the collection of soil samples (Red-Yellow Latosol) and plant residue: native forest (Forest), renewed banana plantation (R. Banana), old banana plantation (O. Banana), sugarcane (Cane), *crotalaria juncea* (Crotalaria) and pasture of Colonial grass (Pasture).

The Latosol in the area of the old banana plantation had been under a monocrop of the ‘Dwarf Prata’ banana for 14 years. This plantation had micro-sprinkler irrigation and received one annual fertilisation corresponding to 200 kg ha^{-1} N and 250 kg ha^{-1} K_2O.

The renewed banana plantation was also cultivated with ‘Dwarf Prata’ with micro-sprinkler irrigation, and had been planted about 1.5 years earlier, with the soil prepared by heavy harrowing; the area originated in the banana monocrop of the previous treatment (banana for 14 years). In this treatment, fertilisation was carried out for each hole with 10 L of bovine manure, 120 g P_2O_5 and 60 g K_2O, in addition to a cover fertilisation during the first year of 200 kg ha^{-1} N and 280 kg ha^{-1} K_2O. The sources of N, P_2O_5 and K_2O were urea or ammonium sulphate, monoammonium phosphate (MAP) and potassium chloride respectively.

Preparation of the soil for the sugarcane (established two years earlier) and *crotalaria* (cultivated yearly for five years) was carried out conventionally by ploughing and harrowing, with the areas receiving earlier crops of annual plants, such as maize and beans. When planting the sugarcane, fertilisation was carried out by the application of 120 kg ha^{-1} P_2O_5 and 60 kg ha^{-1} K_2O as NPK. The *crotalaria* was grown with no planting or cover fertilisation, aiming at an end production of green manure.

The area of pasture had been cultivated with Colonial grass for approximately three years; soil preparation when setting up the pasture was also conventional, with the use of ploughing and harvesting. At the time of planting, the pasture received a single dose of phosphate fertilisation (80 kg ha^{-1}) with the application of single superphosphate, and at the start of the wet period, fertilisation was carried out with 50 kg ha^{-1} N in the form of urea during each year of cultivation.

Soil samples were collected at depths of 0-0.2, 0.2-0.4 and 0.4-0.6 m (three single samples to make up one composite sample) during the rainy season, using a Dutch auger; the samples were then air-dried, declumped using 2-mm mesh sieves, and homogenised for chemical and physical characterisation (Table 1). Undisturbed clumped samples were also collected at these sites and depths using a hoe (clumping method), as per the Empresa Brasileira de Pesquisa Agropecuária (1997), to estimate the apparent density of the soil (Table 1).

At the same sampling sites, three single soil samples were collected with the aid of a template (0.5 x 0.5 m) thrown randomly onto the soil surface, to make up one sample composed of plant residue. The experimental design was in randomised blocks (RBD) with three replications.

Determination of the carbon and nitrogen in the plant residue

The collected plant residue was dried in a forced-ventilation drying oven at 60 ºC to constant moisture. The samples were then ground in a Wiley mill and passed through a 1-mm mesh sieve. From the samples of plant residue, the dry matter weight and the levels (TEDESCO; BOHNEN; VOLKWEISS, 1995) and stocks of C and N were quantified.

The stocks of C and N in the plant residue were calculated by multiplying the C and N content by the dry matter weight of the plant residue as per equation 1:

$$S = \text{content x weight}/100 \quad (1)$$

where: S = stock of C or N (t ha^{-1}), content = C or N content (dag kg^{-1}), weight = dry matter weight (t ha^{-1}), 100 = unit conversion factor.

Determination of the total organic carbon and total nitrogen in the soil

Sub-samples of the soil (ADFE) were ground and passed through a 100-mesh (0.149 mm) sieve to determine the TOC by the wet oxidation method with external heating (YEOMANS; BREMNER, 1988). The TN was determined by distillation following sulphuric acid digestion (BATAGLIA *et al*., 1983).

Fractionation of the humic substances

Soil samples, after being macerated and passed through a 100-mesh (0.149 mm) sieve, were subjected to fractionation of the humic substances, following the method suggested by the International Humic Substances Society (SWIFT, 1996). From this fractionation, the fulvic acid fractions (FAF), humic acid fractions (HAF) and humin fractions (HF) were determined based on the differential solubility in acid or alkaline solutions. The humic substances (HS) were obtained from the sum of all these humic fractions. The C in each humic fraction was determined by the wet oxidation method with external heating, proposed by

Table 1 - Chemical and physical characteristics of the Red-Yellow Latosol (0-0.2 m layer) collected in the areas of native forest (Forest), renewed banana plantation (R. Banana), old banana plantation (O. Banana), sugarcane (Cane), *crotalaria* (Crotalaria) and pasture (Pasture) in the region of Nova Porteirinha

Crop	[1]pH	[2]TOC	[3]P	¬¬ [3]K	[4]Ca^{2+}	[4]Mg^{2+}	[5]H+Al	Clay	Dens.
			------- mg dm^{-3} --------		------------- $cmol_c$ dm^{-3} -------------			%	kg dm^{-3}
Forest	5.10	1.52	2.55	65.32	1.20	0.52	2.98	31.00	1.20
R. Banana	6.00	1.79	25.23	130.43	3.81	1.10	1.41	29.00	1.23
O. Bananal	6.50	1.57	200.10	180.18	3.17	0.93	1.24	30.00	1.36
Cane	5.80	1.56	180.12	110.22	2.92	0.85	2.50	28.00	1.40
Crotalaria	6.00	1.66	50.15	85.16	2.80	0.88	1.75	32.00	1.36
Pasture	5.60	1.55	11.16	70.12	1.95	0.72	2.65	31.00	1.29

[1] pH in H_2O; [2] Total Organic Carbon (COT), as per Yeomans e Bremner; [3], Extrator: Mehlich 1; [4], Extrator: KCl^{-1} mol L^{-1}; [5] Extrator: 0.5 mol L^{-1} calcium acetate - pH 7.0

Yeomans and Bremner (1988); the N was determined by the Kjeldahl method.

The stocks of C and TN in the soil layers were calculated by multiplying the C and N content, the bulk density and the depth of the layer, as per formula 2:

S = contet x density x dept (2)

where: S = stock of C or N (t ha^{-1}), content = C or N content (dag kg^{-1}), density = bulk density (kg dm-3), depth = depth of soil layer (cm).

The data were submitted to analysis of variance. Then, according to the significance of the analysis of variance, the Scott-Knott test at 5% was used to compare the mean values, using the Sisvar 5.3 statistical software (FERREIRA, 2010).

RESULTS AND DISCUSSION

Carbon and nitrogen in the plant residue

The mean C content in the plant residue varied between 23 and 41 dag kg^{-1} (Table 2). The residue from the renewed banana plantation and the crotalaria obtained the highest mean values, with the plant residue from the native forest, sugarcane and old banana plantation presenting the lowest levels for C. The N content in the plant residue ranged from 0.5 to 2.5 dag kg^{-1}, decreasing in the following order: *crotalaria* > pasture > native forest > renewed banana plantation = old banana plantation > sugarcane (Table 2).

The residue from the crotalaria had the highest levels of N (2.5 dag kg^{-1}) among the cropping systems (Table 2), due to the legume presenting symbiosis with N-fixing microorganisms, which are able to increase N in the plant tissue. Similarly, the highest stock of TN was seen in the *crotalaria*, with 0.34 t ha^{-1} N, differing statistically from the other cropping systems, but lower than the stock of N obtained in the native forest residue (Table 2). According to Moda *et al*. (2014), among the main cover crops grown in the District of Jaboticabal, São Paulo, (e.g. *crotalaria-juncea*, jack bean, field bean, millet, and velvet bean), *crotalaria-juncea* accumulated 213 kg ha^{-1} N, with the production of 18.5 t ha^{-1} of dry matter. One of the advantages of cultivating legumes such as *crotalaria*, is the larger stock of N in the crop residue, which may contribute to the nutrition of successive crops (AITA; GIACOMINI, 2003) and increase the stock of TN in the soil.

The greatest accumulation of plant-residue dry matter on the soil surface was seen in the native forest (49.4 t ha^{-1}) compared to the levels of accumulation determined in the cropping systems (Table 2), which showed no difference between one another. The greatest value for dry-matter weight resulted in greater stocks of C and TN in the native-forest residue (11.5 and 0.7 t ha^{-1} C and TN respectively). In contrast, the smallest stocks of

Table 2 - Levels and mean values of carbon and total nitrogen (TN) and the C/N ratio in plant residue deposited on the soil surface of different types of crop in the northern region of the State of Minas Gerais

Crop	Content		Stock			C/N
	TOC	TN	DM	TOC	TN	
	------------- dag kg^{-1} -------------		------------------------ t ha^{-1} ------------------------			
Native forest	23.07 b	1.33 c	49.44 a	11.54 a	0.66 a	17.25 b
R. Banana	41.13 a	0.90 d	8.81 b	3.64 b	0.08 c	47.78 a
O. Banana	26.48 b	0.83 d	21.45 b	5.56 b	0.18 c	31.62 b
Cane	22.70 b	0.50 d	13.95 b	3.04 b	0.07 c	45.35 a
Crotalaria	41.00 a	2.50 a	13.58 b	5.64 b	0.34 b	16.35 b
Pasture	33.53 a	1.77 b	12.82 b	4.24 b	0.22 c	19.42 b
Mean	31.32	1.31	20.01	5.61	0.26	29.63
Source of variation	--- Mean square ---					
BlocK	50.89^{ns}	0.02^{ns}	0.38^{ns}	1.00^{ns}	0.01^{ns}	85.33^{ns}
Cropping systems	216.38*	1.61*	673.82*	28.48*	0.15*	608.51*
Residue	27.59	0.06	24.50	3.07	0.01	89.73
CV(%)	16.77	19.36	24.74	31.05	32.01	31.97

Mean values followed by the same lowercase letter in the columns do not differ at 5% by Scott-Knott test. CV(%): coefficient of variation as a percentage. ns, *, not significant and significant at 5 % respectively by F-test in the analysis of variance

C and TN were obtained in the sugarcane crop (3.0 and 0.07 t ha^{-1} C and TN respectively), with no difference from those seen in the renewed banana plantation, old banana plantation or pasture. Such results indicate that the native forest ecosystem has the greatest potential for increases in SOM, due to the greater stocks of C and TN in the plant residue.

The *crotalaria* and native-forest residue achieved the lowest C/N ratios, with mean values of 16 and 17 respectively (Table 1), demonstrating the greater lability of these residues compared to those of the renewed banana plantation (C/N = 48) and sugarcane (C/N = 45).

Under semi-arid conditions, plant residue with a higher N content and lower C/N ratio, such as *Ricinus communis*, *Gliricidia sepium*, *Atriplex* spp and *Leucaena* spp, showed a capacity for the liquid mineralisation of N in the soil (ALVES *et al*., 2011). However, those authors pointed out that the decomposition of plant residue and the formation of SOM are also dependent on the levels of polyphenols and lignin in the cultivated species. Usually, residue with a higher lignin content delays the formation of organic matter due to its recalcitrance. Furthermore, the influence of phenolic compounds on the process of N mineralisation is due to the polyphenols forming complex structures through stable bonds (hydrogen bridge bonds and covalent bonds, among others) with nitrogen groups (amino groups, for example) and nitrite (NO_{-2}) leaving the materials resistant to decomposition, or resulting in the incorporation of N into the more recalcitrant fractions of the soil organic matter (ALVES *et al*., 2011).

Stocks of carbon and nitrogen in soils cultivated with different plant species

The greatest stocks of C and TN were seen in the soil surface layers, with approximately 38.7 and 32.6 t ha^{-1} TOC and 4.4 and 3.6 t ha^{-1} TN respectively, at depths of 0-0.2 and 0.2-0.4 m (Table 3). Only in the 0-0.2 m layer, was there an accumulation of 42% of the TOC and TN present in the soil to a depth of 0.6 m. The results of this study were similar to those obtained by Costa *et al*. (2009), Freixo *et al*. (2002) and Gatto *et al*. (2010), who reported a decrease in the levels and stocks of TOC and TN with increases in soil depth.

The stocks of soil C did not differ between the cropping systems and the native forest in the surface layers (0-0.2 and 0.2-0.4 m) or in the 0-0.6 m layer (Table 3). At a depth of 0.4-0.6 m, a greater stock of TOC was obtained under the pasture, *crotalaria* and sugarcane crops compared to the stocks obtained in the other systems. Such results demonstrated that the agricultural systems are maintaining stocks of soil C, in comparison to the native vegetation, even with less deposition of vegetal residue on the soil surface, as described in Table 2. Maia *et al*. (2009) reported that agricultural or pastoral crops can contribute to the storage of soil C; however, for this to be possible, it is important to adopt techniques of conservation management that favour maintenance of the physical, chemical and biological properties of the soil.

Similarly, Oliveira *et al*. (2013) found that converting a more intensive cropping system (annual crops with maize and beans) to a less intensive system (guava and irrigated banana) in the semi-arid region of the Northeast, promoted the recovery of the total soil C and N stocks, especially on the surface, even in areas that were intensely cultivated in the past. Pringle *et al*. (2014) noted the loss of 84 kg ha^{-1} TN and a reduction in C stock in the 0.1 m layer of soil in the semi-arid region of northern Australia during a 26-year grazing period (*Astrebla* spp.), with an increase in grazing intensity. Alvarez *et al*. (2014) described how the adoption of a conservation cropping system (direct planting) and the inclusion of grass (maize) in a system of crop rotation with soy bean was fundamental for the increase of C and N stocks in the soil under the semi-arid climate of the Argentinian Pampas.

Stocks of TN in the 0-0.6 m layer were higher in the soil of the sugarcane, crotalaria, renewed banana plantation and pasture than in the old banana plantation, and did not differ from the stock of TN in the soil of the native forest (Table 3). For the other soil layers (0-0.2, 0.2-0.4 and 0.4-0.6 m), there was no difference in TN stock between the soils of the cropping systems and the native forest, further indicating maintenance of the TN stock in most of the cultivated soils in comparison to the native forest. The lower TN stock in the soil of the old banana plantation was explained by a possible reduction in the rate of N mineralisation in lignified residue from the old banana plantations; in the 0.2-0.4 m layer, a higher C/N ratio was found in the soil of this cropping system (Table 3). These results may indicate the lower efficiency of the old banana plantation ecosystem in converting plant residue to SOM, since N is an essential element in the synthesis of humic substances (STEVENSON, 1994), and evidence suggests that it plays an important role in the humification and formation of stable organic compounds in the soil (DIJKSTRA *et al*., 2004). According to Alves *et al*. (2011), woody plant materials cultivated in the semi-arid region, such as the stalks of *Pennisetum purpureum*, *Cenchrus ciliaris* grass and the branches of *Senna sectabilis* and *Sida cordifolia*, when incorporated directly into the soil, cause the immobilisation of N due to the high lignin/N and polyphenol/N ratios.

Table 3 - Stocks of carbon and nitrogen, the C/N ratio and bulk density in the 0-0.2, 0.2-0.4, 0.4-0.6 and 0-0.6 m layers of soils submitted to different types of crop in the northern region of the State of Minas Gerais

Crop	TOC	TN	C/N	Ds
	---------- t ha^{-1} ----------			kg dm^{-3}
---------- 0.0-0.2 m ----------				
Native forest	43.04 a	4.19 a	9.96 a	1.23
Renewed banana plantation	37.80 a	4.90 a	8.04 a	1.36
Old banana plantation	37.58 a	3.11 a	12.30 a	1.40
Sugarcane	39.93 a	5.11 a	8.62 a	1.36
Crotalaria	36.61 a	5.52 a	6.59 a	1.20
Pasture	37.43 a	3.71 a	10.14 a	1.29
Mean	38.73	4.42	9.28 a	1.31
CV(%)	24.52	27.92	22.03	
---------- 0.2-0.4 m ----------				
Native forest	33.13 a	3.83 a	8.65 b	1.38
Renewed banana plantation	28.19 a	3.27 a	9.85 b	1.40
Old banana plantation	29.03 a	1.28 b	25.22 a	1.33
Sugarcane	30.95 a	4.19 a	7.56 b	1.36
Crotalaria	32.22 a	4.19 a	9.08 b	1.26
Pasture	42.09 a	4.77 a	10.30 b	1.15
Mean	32.60	3.59 a	11.78 b	1.31
CV(%)	27.06	25.26	20.10	
---------- 0.4-0.6 m ----------				
Native forest	14.28b	2.87a	5.04b	1.39
Renewed banana plantation	14.53b	2.20a	6.63b	1.37
Old banana plantation	16.18 b	2.62 a	6.34 b	1.34
Sugarcane	22.89 a	2.60 a	10.51 a	1.31
Crotalaria	27.15 a	1.65 a	16.66 a	1.26
Pasture	31.00 a	2.58 a	18.67 a	1.24
Mean	21.00	2.42	10.64 a	1.32
CV(%)	20.05	35.57	32.10	
---------- 0.0-0.6 m ----------				
Native forest	90.45 a	10.88 a	8.31 a	1.34
Renewed banana plantation	80.52 a	10.37 a	7.77 a	1.37
Old banana plantation	82.79 a	7.02 b	11.80 a	1.36
Sugarcane	93.76 a	11.90 a	7.88 a	1.34
Crotalaria	95.97 a	11.36 a	8.45 a	1.24
Pasture	110.51 a	11.06 a	9.99 a	1.23
Mean	92.33	10.43	8.85	1.31
CV(%)	23.62	13.33	25.10	

Mean values followed by the same lowercase letter in the columns do not differ at 5% by Scott-Knott test. CV(%): coefficient of variation as a percentage

Stocks of carbon and nitrogen in the substances

The mean value for C stock in the fulvic acid, humic acid and humin fractions for the 0-0.6 m layer corresponded to 15.8, 9.1 and 53.7 t ha^{-1} respectively (Table 4). Among the cropping systems under evaluation, there was a greater stock of C in the HF of the surface layers, for the soils of the banana, sugarcane and crotalaria, compared to those of native forest and pasture (Table 4), showing that annual and perennial cropping systems may contribute to increasing the residence time of C in the soil and to maintaining or increasing the C stock in humic substances. Melo *et al*. (2016) also reported a similar distribution of C in the humic fractions (C-HAF and C-FAF) in areas of irrigated banana and forest in the semi-arid region of the State of Ceará, and attributed these results to the higher input of organic matter (leaves and pseudostem) in the area of banana, and to the lack of soil turning in the area of forest.

In this study, it was found that for the soil under native forest as well as for those under the different cropping systems, most of the C was found in the humin fraction (HF), similar results to those of Silva *et al*. (2016), who reported over 60% of the C in the HF. However, those authors obtained an increase in C stock in the humic substances of soil cultivated with mango after the application of organic compost with different proportions of sheep manure and sugarcane, coconut, elephant grass, castor bean and achiote residue, compared to soils where no residue was applied, and an area of regenerating Caatinga in the semi-arid region of the State of Pernambuco.

The C-HF/(C-FAF+C-HAF) ratio in the soils of the agricultural crops ranged from 1.60 to 3.29 (Table 4). This ratio has been proposed as an indicator of the structural stability of SOM, with an increase in the numerical index indicating greater stability of the C in the SOM (ARAÚJO *et al*., 2011). The cultivated soils under constant turning, especially those with crotalaria (annual crop), had a higher C-HF/(C-FAF+C-HAF) ratio compared to the native forest in the 0-0.6 m layer (Table 4), indicating the greater stability of the C present in the SOM of the agricultural systems, possibly due to an increase in the decomposition rate of the carbon compounds of the SOM, caused by successive soil turning in the agricultural crops. Under these conditions, the proportion of C stabilised in the humin fraction increased. Caetano *et al*. (2013) obtained different results with the conversion of soil under cerrado (native condition of the region) to soya bean grown in succession to millet, with an initial reduction of 1.8 times in the percentage of C in the humin fraction; but after two years of cultivation, there was a recovery of the percentage of humin to higher values, demonstrating the high contribution of the new plant residue to stabilising the carbon in the most humified fraction of humic substances.

Stocks of N in the humic substances differed between the cropping systems, mainly for the fulvic acid and humic acid fractions and the 0-0.2, 0.2-0.4 and 0.4-0.6 m layers (Table 4). On average, the fulvic acid, humic acid and humin fractions had stocks of 0.89, 0.79 and 5.59 t ha^{-1} N respectively, with the humin fraction responsible for a mean accumulation of 77% of the N present in humic substances in the 0-0.6 m layer, showing the high stability of the N present in the SOM, since the humin fraction is considered the most humified of the SOM compartments (STEVENSON, 1994). Under such conditions, N may help in the formation of refractory C (HAGEDORN; SPINNLER; SIEGWOLF, 2003; NEFF *et al*., 2002), resulting in humic accumulation in the soil. A decrease in the C/N ratio was also seen in the most labile fractions (fulvic acid) to the most stabilised (humin) of the humic substances, in the surface and subsurface layers (Table 4), indicating the greater degree of stabilisation and microbial decomposition of the humin fraction of the soils.

In the soil of the renewed banana plantation (at a depth of 0.2-0.4 m) and the crotalaria (at a depth of 0-0.2 m), a higher C/N ratio was seen in the fulvic acid fraction (Table 4), which may indicate a lower degree of decomposition of the organic compounds present in this fraction of humic substances. This may have occurred due to the deposition and incorporation into the soil of plant residue from the previous crop, favouring the entry of partially decomposed residue into the fulvic acid fraction.

The highest stocks of TN in the fulvic acid fraction were obtained in the soils of the old banana plantation and of the pasture in the 0-0.6 m layer, in comparison to the other cropping systems (Table 4). The greater input of roots to the soil under pasture, less soil turning and nitrogen fertilisation of the old banana plantation and of the pasture possibly contributed to obtaining higher stocks of TN in the most labile fraction of the humic substances.

In the humic acid fraction (in the 0-0.6 m layer) the cropping systems had a lower stock of TN compared to the native forest, but in the humus fraction, both the cropping systems and the forest had a similar stock of TN for each soil layer (Table 4). These results indicated that most of the cropping systems increased or maintained the TN stock in the fulvic and humic acid fractions of the humic substances.

Table 4 - Mean values for total organic carbon (TOC), total nitrogen (TN), C/N ratio in the humic fractions (FAF - fulvic acid fraction, HAF - humic acid fraction and HF - humic fraction) and the C-HF/(C-FAF+C-HAF) ratio at depths of 0-0.2, 0.2-0.4, 0.4-0.6 and 0-0.6 m, and in the soils of different types of crop in the northern region of the State of Minas Gerais

Crop	TOC			TN¬			C/N Ratio			H/(AF+AH)
	FAF	HAF	HF	FAF	HAF	HF	FAF	HAF	HF	
	t ha^{-1}									
0.0-0.2 m										
Native forest	4.93 b	3.10 c	15.14 b	0.31 b	0.50 a	2.88 a	16.61 b	6.77 c	5.61 a	1.88 a
R. Banana	5.41 a	2.62 c	13.99 b	0.31 b	0.31 b	1.47 a	17.85 b	8.56 c	10.30 a	1.75 a
O. Banana	5.53 a	1.89 c	18.07 a	0.39 a	0.28 b	2.00 a	14.79 b	6.51 c	8.64 a	2.43 a
Sugarcane	5.21 b	5.52 a	21.49 a	0.25 b	0.28 b	2.79 a	20.71 b	20.73 b	8.40 a	2.01 a
Crotalaria	5.67 a	2.41 c	22.65 a	0.22 b	0.33 b	2.18 a	28.55 a	7.22 c	10.85 a	2.91 a
Pasture	4.86 b	3.85 b	13.18 b	0.30 b	0.14 c	1.55 a	16.89 b	24.63 a	9.27 a	1.51 a
Mean	5.27	3.23	17.42	0.30	0.31	2.14	19.23	12.40	8.84	2.08
CV(%)	4.10	17.04	21.54	17.42	18.65	29.10	19.52	14.62	24.55	24.48
0.2-0.4 m										
Native forest	5.60 a	3.37 a	14.27 b	0.26 b	0.32 a	2.50 a	23.24 b	12.68 b	5.79 b	1.60 c
R. Banana	5.19 a	3.38 a	24.04 a	0.15 c	0.20 a	2.08 a	39.86 a	17.38 a	12.32 b	2.83 a
O. Banana	5.63 a	2.96 a	19.32 b	0.38 a	0.26 a	1.68 a	19.66 b	11.13 b	10.62 b	2.27 b
Sugarcane	5.05 a	2.65 a	22.28 a	0.29 b	0.15 a	2.23 a	17.66 b	19.15 a	9.91 b	2.88 a
Crotalaria	5.14 a	2.52 a	18.50 b	0.26 b	0.12 a	1.86 a	19.69 b	24.72 a	11.89 b	2.57 a
Pasture	5.59 a	2.91 a	19.45 b	0.38 a	0.23 a	1.15 a	14.99 b	12.68 b	18.80 a	2.33 b
Mean	5.37	2.96 a	19.64	0.29	0.21	1.92	22.52	16.29	11.55	2.41
CV(%)	12.88	12.95	11.17	18.53	33.40	30.62	24.96	24.90	26.17	10.15
0,4-0,6 m										
Native forest	5.74 a	2.92 a	12.12 b	0.29 b	0.44 a	1.81 a	22.31 a	6.61 a	6.75 a	1.40 c
R. Banana	5.17 a	2.93 a	15.17 b	0.23 b	0.18 b	1.36 a	23.98 a	16.65 a	12.25 a	1.95 c
O. Banana	5.12 a	2.75 a	19.40 a	0.41 a	0.26 b	1.73 a	12.62 a	14.56 a	11.23 a	2.53 b
Sugarcane	5.15 a	2.78 a	15.69 b	0.29 b	0.26 b	1.26 a	20.09 a	11.40 a	13.17 a	2.03 c
Crotalaria	4.86 a	2.74 a	24.77 a	0.20 b	0.23 b	1.65 a	31.96 a	15.23 a	16.16 a	3.29 a
Pasture	5.09 a	2.80 a	12.76 b	0.41 a	0.26 b	1.38 a	13.12 a	10.92 a	10.03 a	1.62 c
Mean	5.19	2.82	16.65	0.31	0.27	1.53	20.68	12.56	11.60	2.14
CV(%)	10.68	16.75	17.51	18.62	26.18	27.56	37.35	30.08	38.08	14.23
0,0-0,6 m										
Native forest	16.27 a	9.39 a	41.53 a	0.86 b	1.26 a	7.19 a	18.89 a	7.45 b	5.77 b	1.62 c
R. Banana	15.78 a	8.93 a	53.20 a	0.69 b	0.69 b	4.91 a	22.93 a	12.97 a	10.84 a	2.15 b
O. Banana	16.28 a	7.59 b	56.79 a	1.18 a	0.80 b	5.41 a	13.81 a	9.44 b	10.50 a	2.38 b
Sugarcane	15.41 a	10.95 a	59.45 a	0.83 b	0.69 b	6.28 a	18.48 a	15.95 a	9.47 a	2.26 b
Crotalaria	15.67 a	7.67 b	65.92 a	0.69 b	0.68 b	5.68 a	22.79 a	11.24 a	11.60 a	2.82 a
Pasture	15.54 a	9.56 a	45.38 a	1.09 a	0.64 b	4.07 a	14.20 a	15.01 a	11.14 a	1.81 c
Mean	15.82	9.01	53.71	0.89	0.79	5.59	18.52	12.01	9.89	2.17
CV(%)	10.15	10.18	26.99	14.87	19.41	18.15	19.10	16.25	22.14	12.15

Mean values followed by the same lowercase letter in the columns do not differ at 5% by Scott-Knott test. CV(%): coefficient of variation as a percentage. H/(AF+HA): C-HF/(C-FAF+C-HAF) ratio

CONCLUSIONS

1. Agricultural crops have similar stocks of C and TN in plant residue, but lower than those in the native forest;
2. The soils of the cultivated systems and of the native forest have a similar stock of C in the 0-0.6 m layer;
3. The banana, sugar cane and crotalaria cropping systems increase the stock of C in the humin fraction, and the degree of humification of the SOM;
4. The cultivation of crotalaria and the old banana plantation increase the stock of TN in the fulvic acid fraction.

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