Carbon and Nitrogen Stocks Under Different Land-Use in the Paraopeba River Basin-MG Before the Corrégo do Feijão Dam Burst[1]

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ABSTRACT

Soil attributes can provide indicators for the management and conservation of natural and agrarian ecosystems. This study was carried out before the rupture of the Córrego do Feijão dam and aimed to evaluate and quantify the stocks of carbon, nitrogen and the C/N ratio in soils around the Paraopeba-MG river basin in five regions corresponding to the high, middle, and low river course, considering three usage factors: forest, pasture, and Shrubbery forest, correlating them with the chemical and physical properties of the soil, aiming at the interpretation of past use, to obtain management and conservation strategies for ecosystems. The results indicate a significant variation in carbon and nitrogen stocks with an increase in the 20-40 cm layer. Concerning the type of use, the forest system was the most efficient in accumulating carbon. About to site, the regions of Brumadinho and Fortuna de Minas showed similarities in the incorporation of carbon in the soil, differing from the regions of Jeceaba, Florestal, and Três Marias. There was a close correlation between stocks and the chemical and physical properties of the soil, making it possible to assess the quality of the soils in the study regions in terms of structure and fertility.

Keywords: soil chemistry; organic matter; management and conservation of ecosystems.

INTRODUCTION

Understanding the chemical transformations of carbon (C) and nitrogen (N) in the soil is fundamental for the management and conservation of ecosystems, as well as for the proper use of natural resources (Don *et al.*, 2011; Pulido-Fernández *et al.*, 2013; Li *et al.*, 2017; Abu-hashim *et al.*, 2016; Assefa *et al.*, 2017). C and N are the main components of soil organic matter and their stocks will vary depending on the rates of addition, by plant and/or animal residues, and losses, including those resulting from erosion and oxidation by soil microorganisms (Silva, 2012; Franco *et al.*, 2014; Barros *et al.*, 2015). In addition to the biosphere, the chemistry of these elements in the soil system (pedosphere) is closely related to their exchange with the atmosphere and the hydrosphere, providing bases for understanding phenomena such as, for example, the greenhouse effect and eutrophication (Machado, 2005; Nair *et al.*, 2011; Elbasiouny & Elbehiry, 2019).

The stocks of C and N in the soil are also influenced by the management adopted (Victoria *et al.*, 2012). Depending on the use and management, the soil can act as a drain, due to the accumulation of C in the form of organic matter or CO_2 emitting source for the atmosphere (Milne *et al.*, 2007; Schrumpf *et al.*, 2013; Feng *et al.*, 2019). This scenario has changed with the incorporation of conservationist practices (e.g. no-till) that can accumulate values in the range of 30 to 60 Pg of C over 25 to 50 years of cultivation (IPCC, 2006).

On the other hand, the use of conventional management practices with intense soil overturning and the elimination of vegetation cover from the surface, although

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historically presenting a relevant contribution to food production, can significantly affect the stocks of organic matter, leading to intense losses of C and N by mineralization and erosion (Lal, 2004; Jantalaia, 2006; Gelaw *et al.*, 2014; Wang *et al.*, 2016; Li *et al.*, 2017).

Within this context, the Paraopeba River basin, one of the main tributaries of the São Francisco River, which has also been affected by sources of pollutants from the mining industry and whose quality is directly dependent on the proper management of its tributaries, has been showing continuous increase deforestation in its extension by the increase of the population flow, agricultural and mining activities, since the basin is inserted in the region of the Quadrilátero Ferrífero, which act to modify the use and the quality of the soils, as well as of the other compartments of the ecosystem (Cibapar, 2010).

The study of C and N stocks, as well as the chemical and physical attributes of the soil, can provide subsidies for the implementation of adequate management systems, capable of maximizing the sequestration of C and N.

The objective of the present work was to evaluate the C and N stocks, as well as the C/N ratio of the soils around the basin submitted to different systems of use and management, and to relate them to the main chemical and physical attributes of the soils in five regions corresponding to the high, medium and low Paraopeba. Besides, these data would help in future research on the quality of the soils around the basin after the "Córrego do Feijão" dam burst, in the municipality of Brumadinho, on January 25, 2019.

MATERIAL AND METHODS

This study was carried out in five municipalities along the Paraopeba-MG River basin before the Corrégo de Feijão dam burst, areas belonging to the high, middle, and lower stretches of the river (Figure 1). The evaluated municipalities were: Jeceaba (20 ° 32 '6 "S and 43 ° 58' 58" W), located in the upper portion of the river, with climate typology of the *Cfb* type (temperate with mild summer), according to Koeppen, with an average temperature of 22°C and dry season coinciding with winter; Brumadinho (20º 08 '34 "S and 44º 12' 00" W) and Florestal (19º 53 '20''S and 44º 25' 58 "W), located in the middle portion of the river, both with climate type *Cfa* (temperate with hot summer) with an average temperature around 24°C, with a dry season corresponding to winter; Três Marias (18º 12 '21 "S and 45º 14' 31" W) and Fortuna de Minas (19º 33 '39 "S and 44º 26 '49" W), located in the lower portion of the river and which have a climatic typology of the type *Cwa* (rainy and hot summer), with an average temperature of 24°C and dry winter. These regions are characterized by mountainous relief forms, with an average height of 650 m in the mouth of the basin and 1,544 m in the headboard.

The vegetation of the Paraopeba River basin belongs to the Atlantic forest and Cerrado domains since the basin is in a transition area (Cibapar, 2010). Total rainfall ranges around 1,700 mm year^{-1} in the headwater regions and 1,150 mm year^{-1} in the region near the Três Marias dam. These regions were grouped due to the activities that are developed in their surroundings, such as mining (high Paraopeba), sand extraction, agriculture (low and medium river course) and toposequence (flow of organic matter).

The soils were sampled at depths of 0 to 20 cm and 20 to 40 cm, removed at different points in the areas, to obtain more representative samples.

Sampling was carried out considering the following land use and management systems: Native forest, Pasture, and Shrubbery forest (areas in resilience). Shrubbery forests were considered regions during regeneration and with agglomerated vegetation of medium and small sizes. Composite soil samples were taken from these systems, so that a composite sample was formed by two simple samples, generating two sub-samples for each evaluated system. The collected soils were placed in plastic bags, taken to the UFV-CAF laboratory, passed in a 2 mm mesh, and air-dried. After this stage, chemical analyzes were performed (Supplementary Material), according to the methods described by Embrapa and standardized by the current Brazilian Soil Classification System (dos Santos *et al.*, 2018).

Thus, the factors under study, sampling region (five regions, or levels under study: Jeceaba, Brumadinho, Florestal, Fortuna de Minas, and Três Marias), were combined with the management factor (forest, pasture, and shrubbery forest), generating the experimental arrangement (entirely randomized), forming the scheme of factors under study for statistical analysis.

Chemical Analysis

Soil organic C and N content

Soil organic C content was determined by the wet method described by Walkley and Black (1934), as described by Teixeira *et al.* (2017), which consisted of the sulfuric oxidation of the organic material.

To determine the total nitrogen content, the Kjeldahl (1883) method was used, which involves the use of a digestive mixture based on Na_2SO_4 (sodium sulfate) and $CuSO_4$ (copper sulfate). The digestion process was carried out with the aid of a digester block at a high temperature (above 360°C) for five hours with post steam distillation. The distillate was acquired using boric acid (H_3BO_3), together bromocresol green and methyl red, and then titrated with 0.05 mol L^{-1} hydrochloric acid (HCL) until the solution acquired an orange color. Thus, the N content was evaluated in duplicate, with blank tests.

Soil organic C and N stocks

With the organic carbon and N content and soil density, carbon and nitrogen stocks were calculated for each depth sampled using the following equation (Baldotto *et al.*, 2010):

$$C_3 \ or \ N_3 = [C] \ or \ [N_3].p \ . \ SD \ .10 \qquad \text{(Eq. 1)}$$

where *Cs* or *Ns* are the carbon or nitrogen stocks of the soil (Mg ha^{-1}), [C] or [N] the soil organic carbon or nitrogen content (g kg^{-1}), p the thickness of the soil layer (m) and SD is the soil bulk density (Mg m^{-3}).

Physical Analysis

Soil bulk density (g cm^3) was determined for calculating C and N stocks according to Teixeira *et al.* (2017).

Soil chemical attributes

For chemical characterization of the soils in the study areas and also to assist in obtaining the correlation coefficients, the pH in water and the content of P and K available by the Mehlich^{-1} extractor (mg dm^{-3}). Ca^{2+}, Mg^{2+}, and potential acidity ($cmol_c$ dm^{-3}) were determined. Based on the results, the values of the sum of bases (SB), effective CEC (Cations Exchange Capacity), and total CEC ($cmol_c$ dm^{-3}) of base saturation (V%) and aluminum saturation (m%) were calculated. All chemical determinations were based on the standard techniques according to Teixeira *et al.* (2017).

Data analysis

C and N stocks and C/N ratio data were subjected to analysis of variance to verify at each depth the effects of soil use and management systems. The comparisons of the means were made by the Tukey test $P > 0{,}05$, using the the ExpDes package of the R Core software (Ferreira *et al.*, 2014). Pearson's correlation analyzes were performed, with the verification of the significance of the correlation coefficients (r) performed by the Student's t-test. The data were also submitted to cluster analysis (multivariate analysis), using the Euclidean distance to assess the degree of dissimilarity between the samples (Cruz, 2006). Data manipulation was performed using the SPSS 2.0 program.

RESULTS AND DISCUSSION

C, N stocks and C/Ns ratio

C and N stocks, as well as the C/Ns ratio based on stocks, were affected by the different land use and management systems at all depths assessed (Table 1). It is observed that the highest values of C and N stocks for

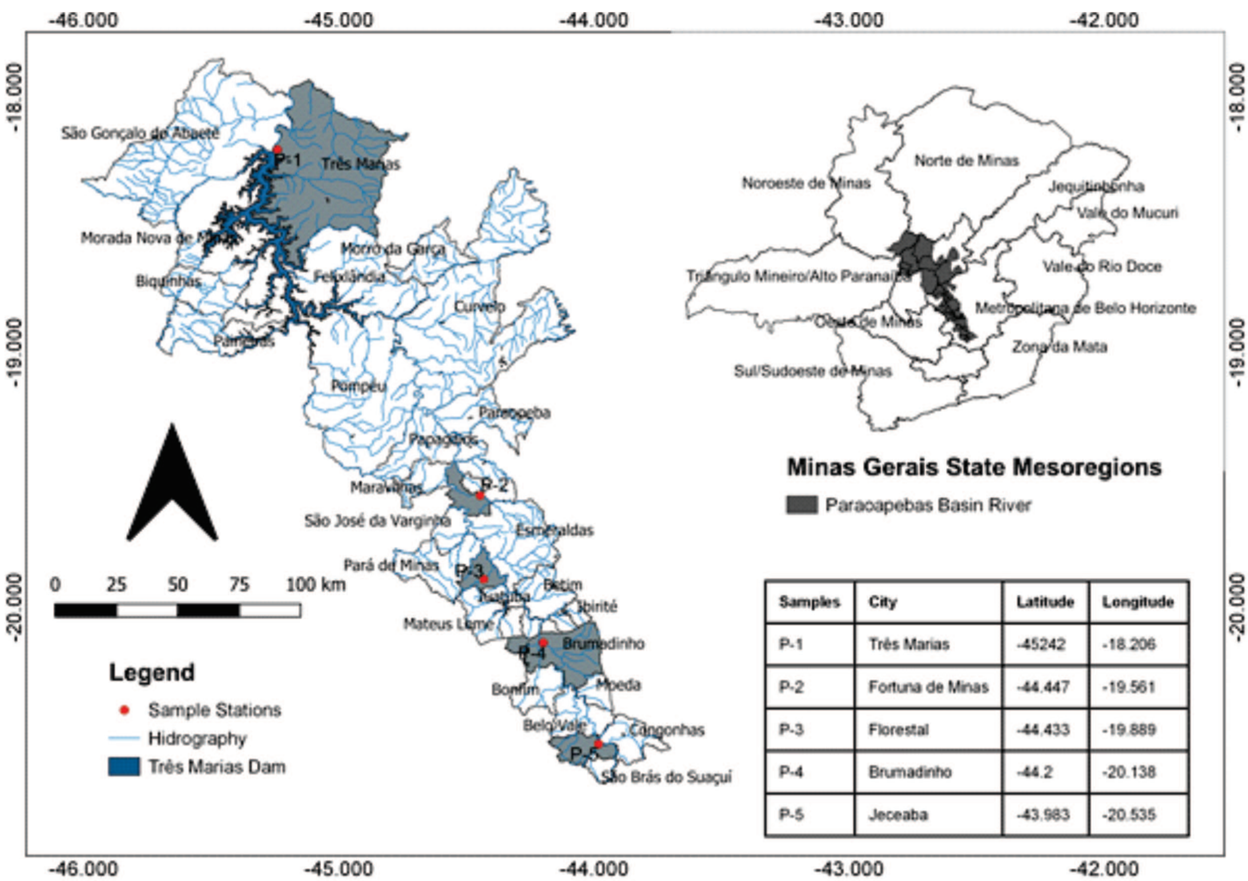

Figure 01: Geographic location of the sampling areas of the Paraopeba River Basin (MG)

the evaluated systems occurred in the subsurface layers (20 to 40 cm). These high values may also indicate the possibility of an A horizon buried (Silva *et al.,* 2012) due to the heavy rains that occurred in 2014.

As for the efficiency in the accumulation of C and N in the five sampled regions, the multivariate analysis of the entire data set generated two dendrograms (Figures 2a and 2b), indicating the division of the analyzed areas, with greater or lesser Euclidean distance.

For C stocks, the cluster analysis generated two groups, one consisting of the municipalities of Jeceaba, Florestal, and Três Marias and a second consisting of the municipalities of Brumadinho and Fortuna de Minas. In the first group, it is noted that the municipality of Jeceaba stands out in its subgroup. The second group represented by Brumadinho and Fortuna de Minas are similar to each other.

For N stocks, there was a formation of three groups, the first subgroup consisting of Brumadinho and Fortuna de Minas, the second formed by Florestal and Três Marias, and the third subgroup formed by the municipality of Jeceaba which stands out from the other groups. Regarding management systems, the results for stocks of C, N, and C/Ns ratio for pastures are shown in Table 1.

The high values of C stock for the depth of 0 to 20 cm were observed in the region of Florestal, belonging to the portion of the middle course of the river. At a depth of 20 to 40 cm, the highest values of C stocks were found in the Brumadinho region, also belonging to the middle portion of the river.

Table 1: Soil carbon and nitrogen stocks (Cs and Ns) and C-to-N ratio (C/Ns) in the pasture system at the 0-20 and 20-40 cm depths

System [(1)]	Depth (cm)		
	0-20		
	C_s	N_s	C/N_s
	Mg ha^{-1}		
PASJ	42,47 b	2,97 a	13,95bc
PASB	43,70 b	2,55 a	15,39b
PASFL	87,58 a	2,90 a	20,80a
PASFM	15,38 b	1,87 b	2,15d
PASTM	39,90 b	3,05 a	6,61c
	20-40		
PASJ	43,68 b	5,25 a	8,79c
PASB	53,73 a	4,24 a	12,09b
PASFL	27,73 c	4,71 a	28,13a
PASFM	7,35 c	1,72 b	2,41d
PASTM	24,3 d	4,30 a	9,93c

[(1)] System: PAS: Pasture; J: Jeceaba; B: Brumadinho; FL: Florestal; FM: Fortuna de Minas; TM: Três Marias. For the pasture system, within each depth, the means followed by the same letter do not differ by Tukey's test ($P > 0.05$).

About the total C stocks (considering the sum of the two sampled depths) the municipality of Florestal had the highest C stock (115, 3 Mg ha^{-1}), accumulating 30% more carbon than others evaluated municipalities.

This high value is because this region has a rotational grazing system could be favoring the regrowth of forages, which justifies the results obtained. Values very close to those verified in this study were found by Freixo (2002) in pastures with 20 years of management, which presented an average stock of 45,6 Mg ha^{-1} of C, which attributed to the voluminous and well-distributed root system of the grasses, which favors the high deposition of C to the soil, mainly in the form of roots.

In general, there was little change in soil N stocks. In the 0 to 20 cm layer, the Três Marias region, located in the portion of the lower course of the river, presented the highest value for the N stock, on the other hand, the Jeceaba region (high Paraopeba) presented the highest value of N stocks at a depth of 20 to 40 cm. When considering the total stock of both depths, the most efficient region for soil N sequestration, it was observed in the Jeceaba region accumulating 8,2 Mg ha^{-1} of N, storing 43% more N than the other regions.

Values very close to those found in this work were observed by Cardoso (2010) when evaluating the stocks of C and N in soils under native forests and pastures in the Pantanal biome, which observed an N stock with an average value of 3,7 to 5,3 Mg ha^{-1} at 0 to 20 cm and 20 to 40 cm layers, respectively.

According to Pulronik *et al.* (2009), this is because plant residues deposited in the soil under natural ecosystems are mainly made up of organic substrates that are difficult to decompose, which contributes to increases in N stocks in the soil. The smallest N stocks observed in the Três Marias region may be related to the quality of pastures in the region, marked by compacted soils with evidence of advanced erosion levels.

It is worth mentioning that the undergrowth of the cerrado suffers eventual episodes of natural burning, with fire being part of the processes occurring in samples from this region. The results obtained for the forest system in the five studied regions are shown in table 2.

It is observed that the C stocks showed a significant difference in the two layers (0 to 20 and 20 to 40 cm) (*Tukey* $P > 0.5$), with the Fortuna de Minas region presenting the highest values at two sampled layers, having a total C stock of 411,5 Mg ha^{-1}, sequestering 77% more C than the other regions under study. The forest sampled in this region was in excellent condition and with little anthropic interference.

The values of soil C stocks from the natural forest from Fortuna de Minas were higher than an area under an Atlantic Forest fragment (Vasconcelos *et al.*, 2010), which was attributed to the greater contribution of organic material on the soil surface, resulting from the fall of leaves, branches, and bark of trees. Thus, a natural system in balance gives the soil greater capacity to retain C.

The lowest values were found in the Três Marias region, which is fully inserted in the Cerrado biome. Reis & Reis (1997) justifies that the low values may result from the fact that the Cerrado is characterized by small plant species, returning smaller amounts of organic material to the topsoil, and, also, these species invest well part of its photoassimilates for the development of a deeper and thicker root system as a way to guarantee the absorption of water and nutrients to meet the plant demand, especially during periods of drought. It is also worth mentioning that the forest, although it has a lower value of C stored in the soil, contributes to high values of stock in biomass.

N stocks also showed a significant difference in the two sampled layers (*Tukey* $P > 0.5$). It should be noted that the Fortuna de Minas region had a higher N stock value in both the superficial and subsurface layers, thus presenting a total stock of 18 Mg ha^{-1}, storing approximately 74% more nitrogen when compared to other regions. Lower results were found before the "Córrego do Feijão" dam burst by Rangel & Silva (2007), which points out that the greater storage of C implies greater availability of N since more than 95% of the N in the soil is present in organic form. The highest C/N ratio calculated based on soil C and N stocks were found in the municipality of

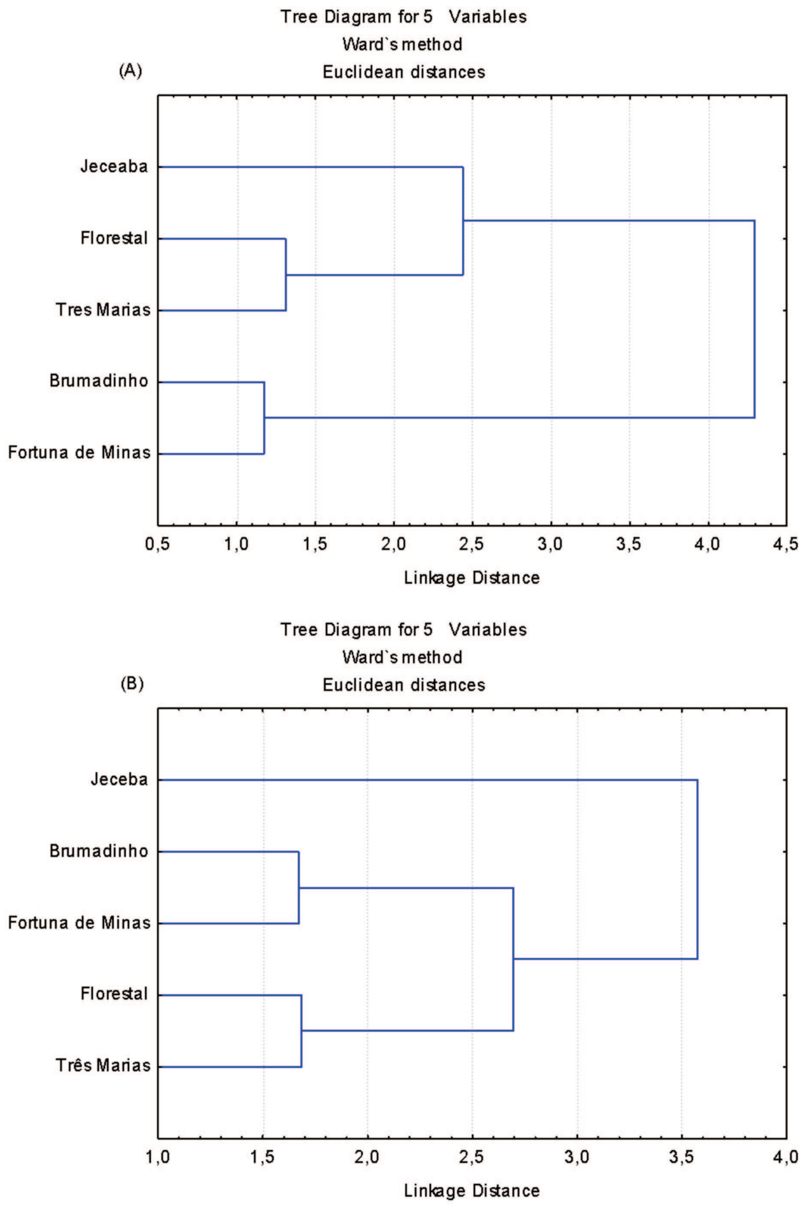

Figure 2: Grouping by the minimum variance and Euclidean distance using multivariate analysis for the data set of the sampled regions: a) dendrogram for C stocks, b) dendrogram for N stocks.

Fortuna de Minas with values of 21 and 15 in the 0 to 20 and 20 to 40 cm soil layers, respectively.

This high C/N_s ratio can be attributed to the coal formed by constant fires events, especially in the middle Paraopeba, where such practices are relatively common. Dick *et al.* (2013) report that organic matter of pyrogenic origin is responsible for increasing the C/N ratio by up to 80%. The lowest values are located in the Florestal region, with 12,2 in the superficial layer and 11,2 in the subsurface layer.

For the shrubbery forest system, the stocks of C, N, and C/N_s ratio are shown in table 3.

It is observed that the Brumadinho region had the highest C stock values in both depths, presenting a total C stock of 182,9 Mg ha^{-1}, sequestering about 39% more C than the same system in the other regions.

According to Rossato *et al.* (2007), high carbon stocks in revegetation areas are related to the rapid recovery of C in the soils of these systems, which may reach, over the years, values close to those found in native forests. For regions where the values of C stocks were low, as observed in the municipality of Jeceaba, it is due to the low C/N ratio, which may have resulted in the rapid mineralization of organic material by microorganisms and with a consequent reduction in C input in the soil.

For N, no significant difference was observed for the superficial layer (0 to 20 cm), however, in the subsurface layer (20 to 40 cm), the largest stocks of N were found in the Florestal region. When considering the total stock of both depths, the Brumadinho region was the most efficient in sequestering C in the soil. It also presents a total N stock of 12,6 Mg ha^{-1}, resulting in an increase of 47% in comparasion to others regions. It was observed that the lowest values are found in the Fortuna de Minas region, with 2,7 Mg ha^{-1}.

This fact may be associated with greater mobility that this nutrient has in the soil. Besides, the lack of vegetation cover may have intensified its losses due to leaching, which justifies the low values observed in this region.

As for the C/N_s ratio, there was no statistical difference in the 20 to 40 cm layer, different from the superficial layer, where the highest values are allocated in the Fortuna de Minas region, with 38,5.

These values differ from the results described in the literature. Favareto (2000) when studying the effect of revegetation and fertilization of soils in degraded areas, found values lower than those verified in the present work, where the average soil C/N ratio at a depth of 0 to 20 cm was 11,3. Mielniczuk (1999), in the work developed with forage species in degraded areas, found a C/N ratio of 12,1. The lowest values are located in the Florestal region, with 12,2 in the superficial layer and 11,2 in the subsurface layer.

Correlations between soil chemical and physical attributes

The chemical and physical attributes of the soils obtained for each management system were correlated using the simple correlation coefficient ($P < 0.05$) which are found in table 4.

The C stocks positively correlated ($P < 0.05$) with Ca^{2+}, SB, t, and T. For N stocks, a positive correlation was observed with the variables Ca^{2+}, SB, and t. The significant

Table 2: Soil carbon and nitrogen stocks (Cs and Ns) and C-to-N ratio (C/Ns) in the forest system at the 0-20 and 20-40 cm depths

System [(1)]	Depth (cm) 0-20 C_s	N_s	C/N_s
	Mg ha^{-1}		
FJ	34,93 b	3,34 ab	12,31c
FB	48,33 b	1,68 c	10,68c
FFL	40,88 b	3,09 bc	13,22b
FFM	205,43 a	4,79 a	21,43a
FTM	8,01 c	2,24 bc	3,56
	20-40		
FJ	41,11 b	3,28 c	12,98 ab
FB	66,30 ab	5,59 bc	11,85b
FFL	87,58 ab	8,74 b	10,02c
FFM	122,78 a	13,24 a	15,07a
FTM	33,79 b	4,21 c	8,03c

[(1)] System: F: Forest; J: Jeceaba; B: Brumadinho; FL: Florestal; FM: Fortuna de Minas; TM: Três Marias. Means followed by the same letter, within each depth of the soil and evaluated system, do not differ by Tukey's test ($P < 0.05$).

Table 3: Soil carbon and nitrogen stocks (Cs and Ns) and C-to-N ratio (C/Ns) in the pasture system at the 0-20 and 20-40 cm depths

System [(1)]	Depth (cm) 0-20 C_s	N_s	C/N_s
	Mg ha^{-1}		
SFJ	23,73 d	1,29 a	20,64b
SFB	60,07 a	5,62 a	21,96b
SFFL	48,55 b	3,97 a	12,22b
SFFM	31,37 c	0,91 a	38,54a
	20-40		
SFJ	39,36 c	3,03 ab	19,98a
SFB	122,78 a	7,00 a	9,31a
SFFL	80,92 b	7,24 a	11,18a
SFFM	41,66 c	1,89 b	22,08a

[(1)] System: SF:Shrubbery forest; J: Jeceaba; B: Brumadinho; FL: Florestal; FM: Fortuna de Minas; TM: Três Marias. Means followed by the same letter, within each soil depth and evaluated attribute, do not differ by Tukey's test ($P < 0.05$).

Table 4: Pearson’s correlation coefficients among the soil attributes[(1)]

	pH	**SOM**	**C**	**N**	**C/N**	**P**	**K**	**Ca^{2+}**	**Mg^{2+}**	**Al^{3+}**	**H+Al**	**SB**	**t**	**T**	**V**	**m**	**BD**	**PT(%)**	**C_s**	**N_s**	**C/N_s**
pH	1	-0,02	-0,02	-0,02	-0,14	0,17	-0,10	0,25	0,29	-0,47*	-0,58**	0,26	0,13	-0,18	0,39*	-0,30	0,13	-0,01	-0,03	0,13	-0,32
SOM		1	0,57**	0,44*	0,03	0,55**	0,21	0,69**	0,25	-0,30	0,01	0,55**	0,59**	0,49**	0,44*	-0,47*	0,38*	-0,49*	0,48**	0,38*	-0,05
C			1	0,70**	0,22	0,49**	0,47**	0,72**	0,34	-0,39	0,43*	0,63**	0,63**	0,85**	0,37*	-0,65**	0,05	-0,11	0,77**	0,50**	0,23
N				1	-0,43*	0,22	0,43*	0,52**	0,30	-0,18	0,25	0,48**	0,53**	0,59**	0,32	0,42*	0,13	-0,03	0,51**	0,59**	-0,19
C/N					1	0,06	0,06	0,01	-0,13	-0,21	0,37*	-0,01	0,07	0,25	-0,12	-0,29	0,10	0,02	0,13	-0,28	0,62**
P						1	-0,04	0,59**	0,27	-0,25	-0,18	0,50**	0,50**	0,30	0,41*	-0,31	0,38*	-0,33	0,38*	0,23	0,01
K							1	0,35	0,40*	-0,37	0,41*	0,42*	0,39*	0,66**	0,37*	-0,57**	-0,32	0,41*	0,11	-0,05	0,17
Ca^{2+}								1	0,71**	-0,53**	-0,15	0,95**	0,93**	0,70**	0,84**	-0,74**	0,24	-0,17	0,74**	0,65**	-0,06
Mg^{2+}									1	-0,64**	-0,39*	0,89**	0,85**	0,56**	0,89**	-0,77**	-0,09	0,27	0,31	0,39*	-0,30
Al^{3+}										1	0,12	-0,56**	-0,35	-0,37	-0,52*	0,76**	0,26	-0,33	-0,32	-0,14	-0,08
H+Al											1	-0,20	-0,15	0,53**	-0,43*	-0,12	-0,16	0,04	0,17	-0,19	0,62**
SB												1	0,97**	0,71**	0,92**	-0,81**	0,14	0,01	0,63**	0,59**	-0,12
t													1	0,72**	0,89**	-0,69**	0,19	-0,08	0,64**	0,65**	-0,16
T														1	0,48**	-0,74**	0,00	0,04	0,66**	0,37*	0,33
V															1	-0,78**	0,17	0,07	0,39*	0,48**	-0,28
m																1	0,10	-0,33	-0,50*	-0,31	-0,12
BD																	1	-0,52**	0,26	0,19	0,04
PT(%)																		1	-0,30	-0,33	0,09
C_E																			1	0,76**	0,22
N_E																				1	-040*
C/N_s																					1

[(1)] Variables: pH = Active Acidity, SOM = Soil organic matter, C = Carbon, N = Nitrogen, P = Phosphorus, K = Potassium, Ca^{2+} = Calcium, Mg^{2+} = Magnesium, Al^{3+} = Aluminum, H + Al = Exchangeable Aluminum, SB = Sum of Bases, t = Effective Cation Exchange Capacity, T = Total Cation Exchange Capacity, V = Saturation Bases, m = Saturation Al^{2+}, BD = Bulk Density, PT = Total Porosity, C_s and N_s = soil C and N stocks, C/N_s = C-to-N stock ratio. ** * Significant at 1 and 5% by t test.

Supplementary material: Chemical analysis of soils in the five sampled regions [(1)]

Site	Sample	Depth	SOM	pH	N	P	K	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	SB	t	T	V	m
	Management	cm	dag kg^{-1}		g kg^{-1}	mg dm^{-3}		$cmol_c dm^{-3}$							%	
Jeceaba	SHRUBBERY FOREST	0 a 20	1,86	4,36	2,81	3,3	78,7	1,65	1,61	0,88	7,55	3,47	4,35	11,02	31,49	20,21
	SHRUBBERY FOREST	20 a 40	1,68	5,3	1,7	2,84	78,7	2,81	2,15	0,15	4,65	5,16	5,31	9,81	52,61	2,85
	FOREST	0 a 20	4,02	6,01	0,59	2,59	40,4	1,47	0,22	0,70	4,20	1,80	2,49	6	29,96	27,95
	FOREST	20 a 40	1,82	7,23	1,25	1,04	21,3	1,14	0,09	0,70	3,45	1,29	1,99	4,74	27,19	35,1
	PASTURE	0 a 20	3,22	4,14	1,22	1,48	37,3	0,88	0,97	1,00	6,95	1,95	2,95	8,9	21,88	33,94
	PASTURE	20 a 40	1,78	4,02	1,04	0,67	11,8	0,63	0,45	0,97	4,50	1,11	2,08	5,61	19,74	46,71
Brumadinho	SHRUBBERY FOREST	0 a 20	1,86	4,36	2,81	3,3	78,7	1,65	1,61	0,88	7,55	3,47	4,35	11,02	31,49	20,21
	SHRUBBERY FOREST	20 a 40	1,68	5,3	1,7	2,84	78,7	2,81	2,15	0,15	4,65	5,16	5,31	9,81	52,61	2,85
	FOREST	0 a 20	4,02	6,01	0,59	2,59	40,4	1,47	0,22	0,70	4,20	1,80	2,49	6	29,96	27,95
	FOREST	20 a 40	1,82	7,23	1,25	1,04	21,3	1,14	0,09	0,70	3,45	1,29	1,99	4,74	27,19	35,1
	PASTURE	0 a 20	3,22	4,14	1,22	1,48	37,3	0,88	0,97	1,00	6,95	1,95	2,95	8,9	21,88	33,94
	PASTURE	20 a 40	1,78	4,02	1,04	0,67	11,8	0,63	0,45	0,97	4,50	1,11	2,08	5,61	19,74	46,71
Fortuna de Minas	SHRUBBERY FOREST	0 a 20	5,79	5,8	0,31	34,84	31,7	4,96	2,29	0,10	2,21	7,33	7,43	9,54	76,83	1,31
	SHRUBBERY FOREST	20 a 40	5,85	5,29	0,38	7,79	31,5	6,00	2,36	0,10	2,69	8,44	8,53	11,13	75,8	1,14
	FOREST	0 a 20	2,08	5,48	1,57	1,69	20,8	0,33	0,00	0,23	1,35	0,38	0,61	1,73	21,99	37,4
	FOREST	20 a 40	1,45	5,44	2,25	1,84	9,7	0,11	0,00	0,29	1,41	0,13	0,42	1,54	8,55	69
	PASTURE	0 a 20	0,59	6,34	0,83	1,78	8,0	0,25	0,64	0,00	3,18	0,91	0,91	4,09	22,25	0
	PASTURE	20 a 40	0,62	5,58	0,42	1,66	12,0	0,26	0,07	0,00	3,50	0,36	0,36	3,86	9,33	0
Florestal	SHRUBBERY FOREST	0 a 20	3,52	4,29	1,67	2,54	59,6	1,85	1,04	0,20	5,85	3,04	3,24	8,89	34,22	6,08
	SHRUBBERY FOREST	20 a 40	2,93	4,29	1,52	1,6	50,0	1,67	0,90	0,33	5,74	2,69	3,02	8,43	31,9	10,87
	FOREST	0 a 20	3,17	4,57	1,39	1,69	78,7	1,81	0,69	0,43	6,60	2,70	3,12	9,3	29,02	13,65
	FOREST	20 a 40	3,17	4,4	1,84	1,06	59,6	1,55	0,59	0,56	7,14	2,29	2,85	9,43	24,33	19,55
	PASTURE	0 a 20	1,84	4,1	1,22	3,15	72,3	0,77	0,15	1,02	6,33	1,11	2,12	7,44	14,88	47,89
	PASTURE	20 a 40	1,18	3,97	1,01	2,08	40,4	0,64	0,21	0,98	5,96	0,96	1,94	6,92	13,87	50,64
Três Marias	FOREST	0 a 20	4,02	4,53	0,87	2	50,0	0,53	0,47	1,17	3,66	1,13	2,30	4,79	23,57	50,92
	FOREST	20 a 40	1,82	4,27	0,8	0,8	12,7	0,36	0,42	1,53	2,80	0,82	2,35	3,62	22,65	65,08
	PASTURE	0 a 20	3,22	4,44	1,18	1,3	35,6	1,24	0,54	1,04	2,37	1,87	2,91	4,24	44,1	35,76
	PASTURE	20 a 40	1,78	4,19	0,87	1,78	10,4	0,64	0,69	2,28	3,12	1,35	3,63	4,47	30,23	62,74

Chemical characteristics: SOM = Soil organic matter = carbon content by the Walkey & Black method x factor 1.724; pH = soil ratio: water in the ratio 1: 2.5; P and K = Mehlich^{-1} extractor; Ca^{2+}, Mg^{2+} and Al^{3+} = KCl 1mol L^{-1} extractor; H + Al = 0.5 mol L^{-1} calcium acetate, pH 7.0; SB = K^{+}, Ca^{2+}, Mg^{2+}; t = SB + Al^{3+}; T = SB + (H + Al); V = (SB / T) x100; m = (Al^{3+} / t) x100.

correlations found between the C stocks and the N stocks with the CEC are of paramount importance since soils with a lower CEC have a greater capacity to lose nutrients by leaching (Bustamante *et al.*, 2006). Thus, high CEC values are also important to increase C stocks, as it is a protective factor for soil organic matter (Lal, 2004).

The C/N_s ratio obtained a significant correlation only with H + Al. This positive correlation may be related to the stabilization of functional groups with buffering capacity at higher pH values, with weaker acid groups. Tus, it results in increased potencial acidity (H + Al) (Baldotto & Velloso, 2014).

CONCLUSION

C and N stocks were more expressive in the subsurface layers (20 to 40 cm). The Fortuna de Minas region was the most efficient in accumulating both C and N, stocking 77% more C and 74% more N than the other regions. Correlation analysis revealed that C and N stocks were correlated with Ca^{2+}, CEC, and SB, showing that regions with high CEC had the highest C stocks and higher fertility. Among the evaluated systems, the forests were the most efficient in the storage of C and N, storing 77% more C and 78% more N concerning pastures and shrubbery forests. Among the systems analyzed, the forests were the most efficient in the sequestration of C and N.

C and N stocks and the C/Ns ratio were sensitive indicators of disturbances resulting from the adoption of different land use and management systems, allowing the evaluation of past use and generating information to monitor the future use of soils in the basin Paraopeba River.

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