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Chemistry, nitrogen and carbon stocks in different land-use systems in a tropical environment

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Considering the occurrence of land degradation and the need for sustainable practices, it is necessary to conduct studies that evaluate the content of organic carbon and nitrogen in the soil, as well as its chemical attributes. Thus, this study aimed to evaluate the content and stock of carbon and nitrogen and the chemical attributes of soil in an area that was classified as a Typic Hapludox and was treated under different land-use systems, a native tropical forest (NF) and agricultural systems with an annual crop (AC), perennial crop (PC) and pasture (PT), located in the southern state of Espírito Santo, Brazil. The content and stock of organic carbon (OC), total nitrogen (TN), the OC/TN ratio and the chemical attributes of land fertility were analysed at depths of 0 to 10, 10 to 20 and 20 to 40 cm. The OC and TN stocks in the soil presented the following descending percentages in relation to the reference system (NF): PC > AC > PT. The percentage reductions in the stocks of OC and TN were 38 and 15%; 42 and 21%; and 8 and 3%, in the PC, AC and PT systems, respectively. Among the cultivation systems that were studied, the native tropical forest and the pasture lands presented the lowest soil fertility, which indicated acidic soils with insufficient macronutrients. Major deficiencies in the micronutrients copper, zinc and boron were observed, and the content of the latter was below a critical level in all of the systems and soil depths evaluated.

Key words: Soil fertility, organic matter, coffee, sorghum, pasture.

INTRODUCTION

The degradation of cropped soil in Brazil is concentrated on pasture lands, annual croplands and perennial plantations. Furthermore, in perennial crops, particularly coffee plantations, the main problems result from erosion caused by steep slope grading, excess weeding, ancient planting with a low density of plants and a low level of conservation practices. Conversely, on pasture lands, the degradation occurs mainly due to soil compaction, lack of

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fertilization, trampling by herds and high rates of pasture use.

The conversion of native vegetation into cropland represents a significant change to the original ecosystem because it generates alterations to the morphological, physical, chemical and biological soil attributes. Thus, some features may be eliminated because the natural mechanisms of recycling and protection are destroyed, which leads to various forms of degradation (Lima et al., 2011; Mansor et al., 2014). The incorporation of carbon (C) and nitrogen (N) into the forest soil is also associated with symbiosis among plants, diazotrophic bacteria and mycorrhizal fungi and contributes a great deal to the plant species that fix atmospheric N (Braghirolli et al., 2012). Ploughing the soil, the extraction of minerals and the imbalanced loss of nutrients from a cropping system cause reductions in the stocks of N and organic C (Nunes et al., 2011).

On cultivated land in tropical areas, organic matter losses occur intensively because their stock may be reduced by more than 50%, when compared with undisturbed areas with the same soil characteristics, in less than ten years of cultivation (Shang and Tiessen, 1997). Up to 80% reductions in carbon content were observed by Silva et al. (1994) in areas cropped with soybeans, and by Silva et al. (1999) in Ferralsols under liming and phosphate fertilisation. Reductions in the C content of agricultural areas are the result of increased organic matter decomposition, which occurs due to the increasing disturbance of soil, the increasing degree of aeration as well as a change in the terrestrial soil structure or the reduction of organic material being introduced into the soil (Dalal and Mayer, 1986).

According to Santos et al. (2008), reduction in the C content may be explained by increased erosion, fast-growing organic matter extraction processes, the organic carbon oxidation processes in the soil, and the smaller quantity of organic material introduced into managed systems, compared with native forests. Souza et al. (2012) claimed that inappropriate soil management may play a fatal role because it creates an opportunity for organic matter mineralization and the emissions of immense amounts of greenhouse gases, such as nitrous oxide (N_2O), carbon dioxide (CO_2) and methane (CH_4) (Cerri et al., 2007). Organic cultivation of coffee is more sustainable than conventional (Partelli et al., 2012), which is also true for sugarcane cultivation, primarily when it does not involve the burning of straw (Evangelista et al., 2013).

The total nitrogen (TN) stock of soil under natural conditions is influenced by climate factors and by vegetation. In soils under a tropical climate, the total nitrogen concentration may vary between 0.02 and 0.40% and, in extreme cases of organic soils (Histosols), it can achieve up to 2% (Stevenson, 1994). The major quantity of total nitrogen in the soil is in its organic form (more than 95%), which makes soil organic matter (OM) a very important reservoir of available forms of N for plants, mainly in the forms of nitric acid ($N\text{-}NO_3^-$) and ammonia ($N\text{-}NH_4^+$) (D'Andréa et al., 2004).

Considering the occurrence of land degradation and the need for sustainable practices, studies that evaluate the stock and content of organic carbon and nitrogen in soil, as well as soil chemical attributes are necessary. Thus, this study aimed to evaluate the content and the stock of carbon and nitrogen and the fertility attributes in a Ferralsol under different land-use systems.

MATERIALS AND METHODS

This study was performed using soil samples from an area classified as a Typic Hapludox on the campus of the Instituto Federal do Espírito Santo (20° 45' 51" S; 41° 27' 24" W and 131 m above sea level) in the Alegre municipality, in the state of Espírito Santo. The climate in the area is considered to be a CWa based on the Köppen system, with a dry winter, an average annual temperature of 23°C and an average annual precipitation of 1,200 mm.

To determine the performance of different land-use systems, four areas were selected, which were distributed in four homogeneous sections of soil. The analysed systems included the following: native tropical forest (NF), annual cropping of sorghum (AC), perennial cropping of coffee (PC) and pasture composed of *Brachiaria* sp. (PT) (Table 1).

Samples were collected in September 2010; in each system, four rectangular blocks, measuring 15×20 m (300 m^2), were selected. Samples were obtained from depths of 0 to 10, 10 to 20 and 20 to 40 cm in order to evaluate the content of organic carbon (OC) and total nitrogen (TN) as well as the chemical attributes of land fertility. Furthermore, one sample from each parcel was removed, which was obtained from 15 randomly chosen subsamples. Each composite sample represented a repetition. To evaluate the soil bulk density characteristics, several undisturbed samples were obtained using a volumetric core with a capacity of 89.53 cm^3. In all of the systems, before collecting the samples, all of the visible plant residues on the land surface were removed.

The samples were kept in plastic bags and were taken to the laboratory. To analyse the content of organic carbon and TN, these were air-dried, ground in a mortar and filtered through a square mesh sieve measuring 0.210 mm. The samples designated for chemical analysis of fertility were air-dried, ground and sieved through 2 mm mesh to obtain the air-dried fine soil TFSA.

The organic carbon was determined using methods described by Yeomans and Bremner (1988). For measuring the NT, the method explained by Bremner (1996) was adopted, which involves the use of a mixture composed of K_2SO_4, $CuSO_4$ and selenium. According to these results, the content of organic carbon and total nitrogen were used to calculate the OC/TN.

The stocks of organic carbon and total nitrogen in the different systems under analysis and at each soil depth were calculated using the following formula: stock of organic carbon or total nitrogen (t ha-1) = content of organic carbon or total nitrogen (g kg^{-1}) × BD × e/10, where BD = bulk density at depth (kg dm^{-3}) (average of four repetitions); and e = the thickness of the soil layer (cm).

On the TFSA samples, the water pH, the changeable contents of Al, Ca, Mg, K, Na, Fe, Cu, Zn, Mn and B, and the available contents of phosphorus (P) (Mehlich-1) and sulphur (S) and the contents H+Al were analysed. The method used to analyse the samples was described by Embrapa (1999). Sulphur extraction was performed using a solution of calcium phosphate (500 mg L^{-1} of P), where the available S was quantified by Turbiquant® turbidimetry. According to data from the fertility analysis, the values of the effective cation exchange capacity (t) and the potential capacity (T), the sum of the

Table 1. History of land-use systems installed in different areas in the municipality of Alegre, Espírito Santo, Brazil.

Land-use systems	Symbol	History
Native forest	NF	A native tropical forest situated approximately 500 m from the other land-use systems with the same soil class. This area was used as a reference for the soil equilibrium state.
Annual crop	AC	This area was previously cultivated with greens for 11 years, after which, in 1994, fodder sorghum (*Sorghum bicolor)* was planted for animal feeding. This crop is planted every year with conventional planting methods and is managed according to proper crop handling protocol. The area remains fallow in the intercrop period.
Perennial crop	PC	This area was previously cultivated with oranges for 23 years, after which, in 2006, a coffee crop was planted (*Coffea canephora).* The crop has been cultivated according to crop handling protocol, including pruning (once a year) when the crop residues are deposited in the crop furrows.
Pasture	PT	This pasture was initially formed with Pernambuco grass, a native species of the region. In 1994, after 64 years, *Brachiaria decumbens* was planted, when the pasture was managed with continuous herbaceous cattle under a semi-intensive regime and with no soil fertility management.

bases (SB), the base saturation (V), the Al saturation (m) and the Na saturation (ISNa) were calculated.

The data from the contents and stocks of organic carbon and TN, the OC/TN and the attributes of soil fertility were subjected to a variance analysis in order to verify the effects of the systems at all depths. Comparisons of the average were performed using Tukey's test, adopting a 5% probability and using the computer app SAEG.

RESULTS

At depths of 0 to 10 cm, the organic carbon content varies from 8.0 to 14.4 g kg^{-1} (Table 2). The organic carbon in the native tropical forest was significantly superior to the annual crop, perennial cropping of coffee and pasture systems. Moreover, in this system, the total nitrogen varied from 0.9 to 1.2 g kg^{-1}, which means a higher total nitrogen content compared with the other systems. The total nitrogen content of the soil was influenced by all of the systems, being higher on the native tropical forest and pasture, at depths of 10 to 20 and 20 to 40 cm. The OC/TN relationship in the soil varied from 9.5 (perennial cropping of coffee) to 11.9 (native tropical forest), from 7.4 (perennial cropping of coffee) to 13.1 (native tropical forest), and from 8.13 (perennial cropping of coffee) to 10.1 (pasture) for samples collected at depths of 0 to 10, 10 to 20, and 20 to 40 cm, respectively (Table 2).

The organic carbon stock was slightly altered by land use at all of the analyzed depths (Table 2). In a general way, considering all of the soil depths, the highest organic carbon stock values were observed in the native tropical forest and pasture systems, followed by the annual crop and perennial cropping of coffee systems. It was observed that the pasture system had an organic carbon stock that was significantly similar to the native tropical forest system (Table 2), according to Rangel et al. (2007).

In general, the total nitrogen stocks in the soil followed the same pattern of answers as the organic carbon stocks (Table 2). The average total nitrogen losses at different depths in the annual crop, perennial cropping of coffee and pasture systems were 19, 21 and 3%, respectively. The potential acidity (H + Al) followed a pattern in which the highest values occurred in the native tropical forest system at all of the evaluated depths, as similarly observed for the pH values. In the annual crop and perennial cropping of coffee systems, at depths from 0 to 10 and 10 to 20 cm, there was no significant difference in the levels of H + Al. Except for the perennial cropping of coffee system at a depth from 20 to 40 cm, the levels of H + Al in the annual crop and perennial cropping of coffee systems were classified as low. Regarding the native tropical forest system, the levels of H + Al were classified as high at depths from 0 to 10 and 10 to 20 cm and were average at depths from 20 to 40 cm.

The P levels at depths from 0 to 10 cm varied from 2 to 32.7 mg dm^{-3}. A greater availability of P at this depth was identified in the annual crop and perennial cropping of coffee systems. In the annual crop system, in which the level of loam is 49%, the P (32.7 mg dm^{-3}) level was high. In the coffee cultivation area (PC) where the soil had a loam level of 38.6%, the P level (23.2 mg dm^{-3}) was also expressed as high. The lowest levels of P were determined in the native tropical forest systems independently of their depths, indicating a generally low P level in the soil.

In the 10 to 20 cm layer in the annual crop and perennial cropping of coffee systems, the P levels were significantly higher than those in the native tropical forest and pasture systems. The same situation was observed at a depth from 20 to 40 cm, despite the lower levels observed in this depth. In all systems, the P decreased with increasing depth.

Availability of Ca and Mg presented a significant variation in the systems of soil usage at all of the

Table 2. Contents of organic carbon (OC), total nitrogen (TN), carbon to nitrogen ratio (C/N), the stocks of organic carbon (EstOC) and the total nitrogen (EstTN) in different land-use systems and at different depths in the municipality of Alegre, Espírito Santo, Brazil.

Land-use system	OC	TN	C/N	EstOC	EstTN
	(g kg^{-1})			(Mg ha^{-1})	
0 - 10 cm					
NF	14.4^{a}	1.2^{a}	11.9^{a}	15.8^{a}	1.3^{a}
AC	10.5^{bc}	0.9^{bc}	11.6^{a}	12.6^{a}	1.1^{a}
PC	8.0^{c}	0.8^{c}	9.5^{a}	10.8^{a}	1.1^{a}
PT	13.0^{b}	1.0^{b}	11.7^{a}	15.7^{a}	1.2^{a}
10 - 20 cm					
NF	9.0^{a}	1.0^{a}	13.1^{a}	14.8^{a}	1.1^{a}
AC	6.5^{ab}	0.7^{b}	8.6^{b}	7.8^{b}	0.9^{a}
PC	5.0^{b}	0.7^{b}	7.4^{b}	6.9^{b}	0.9^{a}
PT	9.3^{a}	0.9^{a}	10.0^{b}	10.8^{ab}	1.1^{a}
20 - 40 cm					
NF	7.7^{ab}	0.8^{a}	9.9^{a}	17.8^{a}	1.8^{a}
AC	5.1^{ab}	0.5^{b}	8.8^{a}	12.5^{ab}	1.4^{b}
PC	4.1^{b}	0.5^{b}	8.3^{a}	10.5^{b}	1.3^{b}
PT	8.0^{a}	0.8^{a}	10.1^{a}	18.2^{a}	1.8^{a}

Native forest (NF), annual crop (Ac), perennial crop (PC) and pasture (PT). Averages followed by the same letter in the column do not differ statistically according to Tukey's test, considering a 5% probability.

evaluated depths (Table 3). At depths from 10 to 20 and 20 to 40 cm, the levels of Ca and Mg presented similar behaviors, with higher amounts in the annual crop and perennial cropping of coffee systems, and significantly lower levels in the native tropical forest and pasture systems. At all of the evaluated depths, the levels of Ca and Mg in the annual crop and perennial cropping of coffee systems are expressed as average. If we consider 2.4 and 0.9 cmolc dm^{-3} as critical Mg and Ca levels in the soil (CFSEMG, 1999), respectively, the levels of these nutrients are only close to or above the value in the annual crop and perennial cropping of coffee systems, except for the Mg level in the pasture system at a depth from 0 to 10 cm, which is a critical level.

The K levels in the annual crop and perennial cropping of coffee systems were within levels that are considered low for native tropical forest and pasture systems at all depths (Prezotti et al., 2007). In the annual cropping system (sorghum), the K level was significantly higher than in the other systems at depths from 0 to 10 cm, which did not differ from the perennial cropping of coffee system at a depth from 10 to 20 cm. From 20 to 40 cm, the highest K level was observed in the perennial cropping of coffee system. The concentrations of K in all of the systems decreased with depth (Table 3). Except for the annual crop and perennial cropping of coffee systems, at depths from 0 to 10 and 10 to 20 cm, the results for all the management systems at different depths are expressed as low (< 60 mg dm^{-3}) in terms of soil fertility related to K.

The results observed in the soil analysis (Table 3) were compared following the fertility patterns of the "5ª Aproximação do Manual de Recomendação de Calagem e Adubação para o Estado do Espírito Santo" (Prezotti et al., 2007) (5th Approach in the Recommendations Manual of Liming and Fertilisation of the State of Espírito Santo).

The pasture system exhibited an Fe level that was significantly higher than that of the other systems at 0 to 10 cm (Table 4), considering that at other depths, there was no consequential variation and the Fe levels were within the medium level range in all of the other systems (20 to 45 mg dm^{-3}) but high in the pasture system (> 45 mg dm^{-3}). In the systems where there was fertilization and liming management (perennial cropping and annual crop), the levels of Mn were significantly higher, with values within the high level range at all of the studied depths. At depths from 0 to 10 and from 10 to 20 cm, the levels of Mn in the native tropical forest and pasture systems did not differ and were considerably lower than those observed in areas with annual and perennial crops.

The soil exhibited a B deficiency in all of the systems and at all depths, which was below or slightly above the designated low level (< 0.35 mg dm^{-3}). The perennial cropping of coffee system presented a considerably higher level of Cu and Zn than the others in the layers from 0 to 10 and from 10 to 20 cm and also of Cu at a depth of 20 to 40 cm (Table 4).

Table 3. Chemical features and macronutrient content at depths of 0 to 10, 10 to 20 and 20 to 40 cm under different land-use systems in the municipality of Alegre, Espírito Santo, Brazil.

Land-use system	pH	S	P	K	Na	Ca	Mg	Al	H+Al
		(mg dm^{-3})			(cmol$_c$ dm^{-3})				
				0 - 10 cm					
NF	4.6^{b}	20.6^{ab}	2.0^{b}	49.5^{c}	3.2^{b}	0.3^{b}	0.5^{b}	0.8^{a}	6.5^{a}
AC	6.0^{a}	25.4^{a}	32.7^{a}	144.7^{a}	12.0^{a}	2.6^{a}	1.1^{a}	0.0^{c}	2.0^{c}
PC	6.1^{a}	2.8^{c}	23.2^{a}	96.0^{b}	4.5^{ab}	2.3^{a}	0.9^{a}	0.0^{c}	2.2^{c}
PT	5.1^{b}	11.3^{b}	1.6^{b}	47.3^{c}	7.5^{ab}	0.5^{b}	0.9^{a}	0.3^{b}	4.1^{b}
				10 - 20 cm					
NF	4.6^{b}	24.2^{a}	1.5^{b}	28.7^{b}	1.7^{b}	0.1^{b}	0.4^{b}	0.9^{a}	5.2^{a}
AC	5.9^{a}	33.3^{a}	28.3^{a}	63.0^{a}	15.0^{a}	2.4^{a}	0.9^{a}	0.0^{c}	1.7^{c}
PC	6.5^{a}	0.7^{b}	20.7^{a}	64.2^{a}	4.0^{b}	2.3^{a}	0.9^{a}	0.0^{c}	1.2^{c}
PT	5.0^{b}	14.9^{ab}	1.3^{b}	17.7^{b}	6.2^{ab}	0.4^{b}	0.5^{b}	0.3^{b}	3.2^{b}
				20 - 40 cm					
NF	4.6^{c}	28.0^{a}	1.4^{c}	17.0^{b}	0.0^{b}	0.0^{b}	0.4^{b}	0.8^{a}	4.5^{a}
AC	6.0^{b}	25.8^{a}	11.7^{a}	22.0^{b}	5.2^{a}	2.1^{a}	0.9^{a}	0.0^{c}	1.5^{c}
PC	6.9^{a}	6.4^{b}	4.9^{b}	49.3^{a}	3.2^{a}	2.1^{a}	0.9^{a}	0.0^{c}	3.5^{b}
PT	5.2^{c}	16.8^{ab}	1.2^{c}	11.7^{b}	6.0^{a}	0.3^{b}	0.2^{b}	0.4^{b}	0.6^{d}

Native forest (NF), annual crop (Ac), perennial crop (PC) and pasture (PT). Averages followed by the same letter in the column do not differ statistically according to Tukey's test, considering a 5% probability.

Table 4. Fertility attributes at depths of 0 to 10, 10 to 20 and 20 to 40 cm under different land-use systems in the municipality of Alegre, Espírito Santo, Brazil.

Land-use system	t	T	SB	V	m	ISNa	Fe	Cu	Zn	Mn	B
	(cmol$_c$ dm^{-3})			(%)			(mg dm^{-3})				
					0 - 10 cm						
NF	1.9^{c}	7.18^{a}	1.0^{b}	14.6^{c}	45.4^{a}	0.1^{b}	59.9^{b}	0.3^{c}	1.0^{b}	13.1^{b}	0.4^{a}
AC	4.2^{a}	6.0^{b}	4.2^{a}	69.9^{a}	0.0^{c}	0.8^{a}	43.9^{b}	1.1^{b}	4.1^{b}	83.6^{a}	0.1^{b}
PC	3.5^{b}	5.7^{b}	3.5^{a}	60.8^{a}	0.0^{c}	0.3^{ab}	40.9^{b}	3.6^{a}	17.0^{a}	114.2^{a}	0.1^{b}
PT	1.9^{c}	5.8^{b}	1.6^{b}	27.5^{b}	16.3^{b}	0.5^{ab}	85.2^{a}	0.7^{bc}	1.0^{b}	28.7^{b}	0.1^{b}
					10 - 20 cm						
NF	1.5^{b}	1.5^{b}	0.6^{b}	10.5^{b}	60.0^{a}	0.1^{b}	48.3^{a}	0.3^{b}	0.6^{b}	5.0^{c}	0.3^{a}
AC	3.9^{a}	3.9^{a}	3.9^{a}	69.0^{a}	0.0^{c}	1.0^{a}	34.8^{a}	0.8^{b}	3.2^{ab}	56.0^{b}	0.1^{b}
PC	3.5^{a}	3.5^{a}	3.5^{a}	73.4^{a}	0.0^{c}	0.4^{b}	42.5^{a}	2.9^{a}	3.1^{a}	92.9^{a}	0.1^{b}
PT	1.4^{b}	1.4^{b}	1.0^{b}	21.9^{b}	25.8^{b}	0.6^{ab}	43.4^{a}	0.6^{b}	0.4^{b}	17.0^{c}	0.1^{b}
					20 - 40 cm						
NF	1.3^{b}	1.3^{b}	0.5^{b}	9.4^{c}	64.2^{a}	0.9^{a}	42.5^{a}	0.3^{b}	0.4^{a}	3.2^{a}	0.3^{a}
AC	3.1^{a}	3.1^{a}	3.1^{a}	67.1^{b}	0.0^{c}	0.5^{a}	27.1^{a}	0.4^{b}	0.6^{a}	17.3^{a}	0.0^{b}
PC	3.1^{a}	3.1^{a}	3.2^{a}	82.9^{a}	0.0^{c}	0.4^{a}	35.2^{a}	1.3^{a}	1.8^{a}	29.5^{a}	0.0^{b}
PT	1.2^{b}	1.2^{b}	0.8^{b}	18.9^{c}	35.7^{b}	0.6^{a}	32.7^{a}	0.5^{b}	0.2^{a}	8.6^{a}	0.1^{b}

Native forest (NF), annual crop (Ac), perennial crop (PC) and pasture (PT). Averages followed by the same letter in the column do not differ statistically according to Tukey's test, considering a 5 % probability.

According to the CFSEMG (2009), the critical soil levels of micronutrients presented in the Table 4 are Fe = 30 mg dm^{-3}; Cu = 1.2 mg dm^{-3}; Zn = 1.5 mg dm^{-3}; Mn = 8.0 mg dm^{-3}; and B = 0.6 mg dm^{-3}. Thereafter, the evaluated soil in the different systems at several depths exhibit the following micronutrient deficiencies: Cu (in the annual crop and perennial cropping of coffee systems in the depth from 0 to 10 cm); Zn (in the native tropical forest and pasture systems at all depths, and annual crop at a depth of 20 to 40 cm); Mn (in the native tropical forest system at depths from 10 to 20 and 20 to 40 cm); and B (in all of the studied systems and depths).

The native tropical forest system presented a significantly higher value than in the annual crop, pasture and perennial cropping of coffee systems at depths from 0 to 10 cm (Table 4). At depths from 10 to 20 and from 20 to 40 cm, the annual crop and perennial cropping of coffee systems presented CEC values significantly higher than in the native tropical forest and pasture systems. The values of CEC numerically decreased in the soil profile. The saturation base (V) exhibited a significantly higher value in the annual crop and perennial cropping of coffee systems at all depths (Table 4). The values of base saturation, pH, Al, H+Al, Al saturation, Ca and Mg at depths from 0 to 10 and 10 to 20 cm were considered as expected.

DISCUSSION

The significantly superior organic carbon (OC) in the native forest (NF) than in the annual crop (AC), perennial crop (PC) and pasture (PT) systems (Table 2) can be explained by the historically more intensive soil ploughing and consequently higher C loss by oxidation and erosion. However, when the use of the agricultural systems is balanced or organic, soil sustainability can be reached (Partelli et al., 2012; Evangelista et al., 2013).

For tropical soils that are not ploughed, there is a balance in the OC/TN relationship of approximately 10 to 15 (Stevenson, 1994). The low values in this relationship observed in the annual crop and perennial cropping of coffee systems may occur due to the high pH level and the lack of Al in the soil (Table 3), which are factors that benefit the increase in OM (Stevenson, 1994). Despite not having detailed information about handling the soil fertility in the systems that were cultivated with sorghum and coffee for a long period leading up to this experiment, it is possible to affirm that nitrogen fertilization that was performed over the years created favorable conditions for growth in the total nitrogen content and a consequent reduction in the values of the OC/TN relationship.

The systems with less intensive or no soil ploughing tended to maintain more OC, which was observed at depths of 10 to 20 and 20 to 40 cm (Table 2). According to Paul and Clark (1989), the augmentation of the organic carbon stock in soils subjected to more conservation systems may be associated with the physical protection of organic compounds against microbial decomposition, which benefit from the occlusion of organic carbon in the soil and result in the chemical protection of organic compounds due to the interaction of the latter with soil minerals and cations such as Al^{3+} and Fe^{3+}, preventing organic carbon decomposition.

The significantly similar organic carbon stock in the pasture system to the native tropical forest system (Table 2), according to Rangel et al. (2007), may be associated with the developed root system and the well-distributed graminae under pasture, which benefits from subsurface carbon deposition in the form of roots.

In the analyzed soil depths, the lowest organic carbon stocks were generally observed in the systems that had greater soil disturbances. In the annual crop system, this was most likely the result of soil aeration and homogenization of the superficial layers by aeration and harrowing. Souza and Melo (2003), studying the impact of different systems in corn production on the dynamics of soil carbon, also observed lower organic carbon stock levels in conventional growing systems when compared to the obtained system values, in which the remains of the previous crops were the soil surface.

The generally same response pattern in total nitrogen as in organic carbon stocks (Table 2) can be explained by the greater amounts of total nitrogen in the soil (approximately 95%) found in association with organic matter. The rise in the total nitrogen stock in the native tropical forest and pasture systems was associated with the greater volume of plant debris that returned to the soil and also to the greater organic carbon stocks in these systems. In a Red-Yellow Argisol subjected to different cropping systems (mineral and organic fertilization), Leite et al. (2003) observed reductions in total nitrogen stocks by 37% in a sample without fertilization and by 15% in systems receiving organic fertilization, in relation to a reference system (native forest), indicating the occurrence of a lower loss of N in the system with greater contributions of organic matter. These results are similar to those of the present study.

For all of the analyzed depths, the active soil acidity (pH) in the native tropical forest system was expressed as ‘high,’ which was followed by the pasture system with active acidity that was expressed as ‘average’. In terms of significant differences, greater pH values were observed in the annual crop and perennial cropping of coffee systems at all of the studied depths.

The pH results reflected liming management in the different systems, which was absent on the forest and pasture lands but was regularly practiced in the annual and perennial cropping systems. The data also indicated advanced stages of weathering and low natural fertility in the analyzed soil. The Al present in the soil solution is hydrolyzed and releases ions H, which are responsible for an elevation in the soil’s active acidity. Another factor that can explain lower pH levels in the native tropical forest and pasture systems is their higher amounts of organic carbon (Table 2). Stevenson (1994) describes the ionization of hydrogen (H) in the carboxylic acid groups and mainly in the tertiary alcohols of organic matter that contribute to soil acidity.

The results of the present study are in line with those obtained by Candido et al. (2010), who evaluated the chemical characteristics of soils under coffee cultivation in the micro region of Caparaó, Espírito Santo, and who found pH values close to those presented in Table 3, in addition to low levels of soil fertility. Significantly, the data obtained indicate the need for the adoption of corrective practices on the pasture lands, which presented high acidity levels and a low Ca content.

The potential acidity (H + Al) followed a pattern similar to that observed for the pH values. The P levels in the soil were generally low. This indicates once more that the management of soil fertility in the pasture area was inappropriate, aside from the naturally low P levels in the soil. Similar results were obtained by Falleiro et al. (2003).

The significantly higher P levels in the annual crop and perennial cropping of coffee systems than in the native tropical forest and pasture systems were associated with the phosphate fertilizer applications. Tropical soils have low P levels because of weathering. In all systems, P decreased in the deeper layers, which can be explained by the greater contribution of organic matter in the surface soil depths (0 to 10 cm), which contributes to a greater availability of P at this depth, in addition to the top-dressing fertilisations and the low P mobility in the soil profile (Falleiro et al., 2003).

Given the importance of Ca and Mg for a good crop development, the results showed the need for additional inputs into the soil in the pasture systems (Table 3). Frazão et al. (2008) evaluated soil fertility in different management systems and also observed lower Ca and Mg levels in the natural and pasture systems. The low levels of these elements in the pasture soil are related to the last application of lime, occurring 18 years before at pasture planting.

The K levels in the annual crop and perennial cropping of coffee systems (Table 3) were similar to results reported in other studies, in which the greatest K concentrations were found in the surface layer of the soil (Santos and Tomm, 2003; Frazão et al., 2008). In the annual crop and perennial cropping of coffee systems, these results were directly associated with the contribution of potassium fertilisers, mainly KCl, which favoured the accumulation of K in the surface soil layers.

According to Silveira and Cunha (2002), the presence of organic matter in the soil is associated with the availability, amount and retention of micronutrients in the soil as B. The higher organic carbon levels in the native tropical forest system (Table 2) explain the higher B level in these soils. The considerably higher level of Cu and Zn in the perennial cropping of coffee system (Table 4) can be explained by foliar fertilisation and soil transport of micronutrients Cu and Zn, performed in isolation.

The significantly higher potential capacity (T) in the native tropical forest system can be explained by the greater contribution of plant residues deposited in the upper soils layers of the native tropical forest system, influencing the increase in organic matter levels at this depth and consequently the potential T. Costa et al. (2006), studying a Rhodic Ferralsol, observed that usage systems where there are greater plant residue inputs present a cation exchange capacity (CEC) that is higher compared to the others systems, which leads to better soil quality in terms of its physical and chemical attributes. The decreasing CEC values in the soil profile were in line with the results of Frazão et al. (2008).

In the annual crop and perennial cropping of coffee systems, there was no need to apply an acid soil corrective (limestone). However, in the pasture system, analyzing the same attributes as previously mentioned, there was an immediate need for intervention in the soil to correct for its acidity. Using the formula of liming need (LN) for the base saturation method and the soil data analysis at depths from 0 to 10 cm, considering that an appropriate base saturation is a good development indicator for pastures, which is expressed as 60% (Prezotti et al., 2007), a limestone with a PRNT ("Poder Relativo de Neutralização Total"; in English, Natural Power of Total Neutralisation) of 100% at a depth of limestone incorporation of 7.5 cm of the surface soil, it would be necessary to apply 720 kg of limestone per hectare on the pasture lands.

Conclusion

The introduction of different systems culminated in the reduction of organic carbon and total nitrogen values, mainly at soil depths of 0 to 10 and 10 to 20 cm.

The stocks of organic carbon and total nitrogen in the soil at the analysed soil depths followed a descending order in relation to the reference system (NF> PC > AC > PT). On average, the percentage reductions in the organic carbon and total nitrogen stocks were 38 and 15%; 42 and 21% and; 8.3 and 3% in the perennial cropping of coffee, annual crop and pasture systems, respectively.

Among the land-use systems analyzed, the areas under native forest and pasture presented lower soil fertility.

Conflict of Interest

The authors have not declared any conflict of interest.

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