Journal of Agricultural Science; Vol. 10, No. 4; 2018
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Soil Chemical Attributes under Crop-Livestock-Forest Integration System and in Different Land Uses in Mata dos Cocais Region

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Received: January 13, 2018 Accepted: February 16, 2018 Online Published: March 15, 2018
doi:10.5539/jas.v10n4p370 URL: https://doi.org/10.5539/jas.v10n4p370

The research is financed by FAPEMA, UEMA and EMBRAPA.

Abstract

The sustainability of ecosystems is closely linked with the assessment of soil properties that estimate their quality. This work proposes to evaluate soil chemical attributes as a function of the implantation of a crop-livestock-forest integration system (ICLF) in the region of Mata dos Cocais in the state of Maranhão, Northeast Brazil. The four different land uses evaluated were native vegetation with babassu, capoeira vegetation, degraded pasture and area under ICLF system (with marandu grass, maize and eucalyptus consortium). The samples were collected up to one meter deep, comprising seven layers: 0.00-0.10, 0.10-0.20, 0.20-0.30, 0.30-0.40, 0.40-0.60, 0.60-0.80 and 0.80-1.0 m. The chemical attributes evaluated were pH, Ca, Mg, Al, P, K and Na, potential acidity, base sum, base saturation and soil cation exchange capacity (CEC). The levels of P, in the 0.00-0.10 m layer, were higher in the ICLF system than those of the native forest with babassu. The levels of K in the ICLF system and degraded pasture were higher than the other land uses up to a depth of 0.40 m, ranging from 0.92 cmolc dm^{-3} to 0.62 cmolc dm^{-3} and 1.04 cmolc dm^{-3} and 0.67 cmolc dm^{-3}, respectively. Base saturation was higher in soils under ICLF system and degraded pasture than those observed in native forest and capoeira vegetation. There was an effect in chemical attributes of the soil such as a function of land use and, in general, the highest values were found in areas with degraded pasture and ICLF.

Keywords: degraded pasture, fertility, babassu forest, soil parameters

1. Introduction

The sustainability of ecosystems is closely linked with the assessment of soil properties that estimate their quality. However, the evaluation of soil quality is not a simple task, given the great complexity of the physical, chemical and biological processes that occur in this environment, its spatial variability and management diversity. For example, surface nutrient accumulation (mainly Ca, Mg, K, P and organic C) may be the result of management techniques that aim at the absence or reduction of soil turnover, as well as the accumulation of residues on the surface and also by the mode of incorporation of the fertilizers (Pereira et al., 2009).

The integration of crop, livestock and forest systems (ICLF) is a technological alternative to the perspective of a more productive and sustainable livestock. Among the benefits of this integration are the conservation of soil and water resources, the promotion of carbon sequestration, the flexibility of cash flow throughout the year and the increase of biodiversity (Vilela et al., 2011). For these authors, as a result, ICLF systems are considered as the solution to many problems inherent to pastures, especially those of an environmental nature. In addition, such systems can be an alternative to overcome the problem of pasture degradation by improving the productive capacity of animals and pastures, improving fertility and soil conservation, minimizing climatic stress on animals, increase profitability by area and add value to the property (Oliveira et al., 2003; Dutra et al., 2004; Martha Junior et al., 2011; Rego et al., 2017).

According to Dias Filho et al. (2006), the forest component, with a root system deeper than forage, promotes the translocation of nutrients and water from lower layers to layers closer to the surface, favoring the development of forages. In addition, the input and decomposition of animal and plant residues (from the forest component and the forage species) increase the cycling of nutrients in the system. However, from the perspective of the rural producer, the environmental benefits attributed to the ICLF system, such as increased biodiversity, environmental conservation and C sequestration, have marginal importance, while low initial profitability and high investment are highlighted, been considered the main barriers to the adoption of this idea (Dias-Filho, 2006; Dias-Filho & Ferreira, 2007).

In Maranhão, livestock activity is predominantly made in an extensive way. In degraded pastures and, in most of the state, it is developed in areas of occurrence of babassu palm trees (Mata dos Cocais). The Mata dos Cocais is a transition formation between the Amazon Forest, Atlantic Forest, Caatinga and Cerrado; located mainly in Maranhão, also occurring in Piauí and in the West of Ceará. There is a wide distribution of babassu forests in the state of Maranhão, places of great difficulty of coexistence between the livestock activity and these palm trees, which results in high degradation of the pastures of Maranhão. Thus, the present work proposes to evaluate the chemical attributes of the soil as a function of the implantation of a crop-livestock-forest integration system in the region of Mata dos Cocais occurrence.

2. Materials and Methods

Soil samples were collected in areas under different land uses in the municipality of Pindaré-Mirim, in the state of Maranhão (3°46′9.12″ S and 45°29′35.52″ W). The climate of the region is classified according to Koeppen (1948), as Aw (hot and humid), with average annual temperature of 26 °C, minimum temperature of 22.3 °C and maximum of 33.5 °C, annual rainfall between 2000 and 2400 mm and relative annual air humidity between 79% and 82% (SEPLAN, 2013; Alvares et al., 2014). The soil of the study area is classified as Hapless Plinthsol, originally covered by tropical forest vegetation, sub-perennial, and dactyl-palmaceous-babassual.

The four different uses of the land evaluated were native vegetation with babassu (*Attalea speciosa* C. Martius), capoeira vegetation (secondary vegetation with approximately 20 years of fallow), degraded pasture (cultivated with *Urochloa brizantha* cv Marandu, with more than 10 years of deployment) and area under ICLF (five months of deployment). The ICLF system was implanted in a degraded pasture area, similar to that of the same denomination sampled in this study. For the implementation of this system, the degraded pasture area was prepared by plowing, sorting and leveling, followed by incorporation (up to 0.20 m depth) of 1.8 mg ha^{-1} of dolomitic limestone. At 60 days after liming the mechanized sowing of the hybrid corn KWS 9304 (spacing 0.6 m × 0.3 m) and the pasture *Urochloa Brizantha* cv. Marandu were made. Fertilization of maize was performed as follows: 400 kg ha^{-1} of the formula (04-30-10 + Zn) at sowing (planting fertilizer). Then 200 kg ha^{-1} of the formula (36-00-30) 10 days after emergence of the corn (First cover fertilization); and a final application of 200 kg ha^{-1} of the formula (36-00-30) 20 days after the first cover fertilization (the second cover fertilization). The tree component of the ICLF system was represented by eucalyptus (*Eucalyptus urograndis*), implanted by seedlings, 70 days after emergence of corn, in double rows with spacing 3.0 m × 2.0 m and 28 m between rows. For eucalyptus, fertilization per pit was carried out with 0.075 kg of phosphate rock at 0.30 m depth and 0.15 kg of fertilizer 36-00-30. At 15 days after sowing the herbicides Atrazina (broad leaf control) and Nicosulforon (an underdose of 1/3 to cause delay in forage development) were applied. At this stage of the ILPF system, cattle were not yet in the field due to the fragility of the forest component structure. Considering the grass as a livestock component.

In each of the four areas, three trenches were opened and, around each trench, in all the cardinal directions, twelve equidistant points were marked. In those points deformed soil samples were collected at the following depths: 0.00-0.10, 0.10-0.20, 0.20-0.30, 0.30-0.40, 0.40-0.60, 0.60-0.80 and 0.80-1.00 m. Around each trench, single samples of the twelve points were combined into a single composite sample for each depth collected. Soil sampling in the area with ICLF was performed after the harvest of the first maize crop.

The samples were sent to the Embrapa Semi-Arid Soils and Vegetable Tissue Analysis Laboratory, where they were air dried and chemically characterized according to Embrapa (1997). The pH in water was determined electronically by means of a combined electrode immersed in soil suspension and water in a ratio of 1:2.5. The exchangeable calcium, magnesium and aluminum contents were extracted with 1.0 mol L^{-1} KCl solution. Calcium and magnesium contents were determined by atomic absorption spectrophotometry and the Aluminum exchangeable determination was done by titration with 0.025 ml L^{-1} NaOH. Available phosphorus, exchangeable potassium and sodium were extracted with Mehlich^{-1} solution (0.05 mol L^{-1} HCl + 0.0125 mol L^{-1} H_2SO_4). Phosphorus was spectroscopically determined by reading the color intensity of the phosphomolybdic complex produced by the reduction of molybdate with ascorbic acid, while exchangeable potassium and sodium were determined by flame emission photometry. The potential acidity (H + Al) of the soil was extracted with 0.5 mol L^{-1} calcium acetate, then determined by titration with 0.025 mol L^{-1} NaOH.

The chemical attributes evaluated were analyzed by Kruskal-Wallis method (non-parametric test), followed by the comparison of means by the Bonferroni test (Dunn) and the confidence intervals around the means were calculated at 95%. All statistical analyzes were performed using the Action Stat 3.0.2 software.

3. Results

The analysis of the texture, density and organic matter of the uses and different depths were carried out to identify possible relationships that could influence the behavior of the chemical attributes in this study (Table 1).

Table 1. Textural characterization, density and organic matter of the soils under different land uses and at different depths in the region of Mata dos Cocais

Land uses	Depth	Sand	Silt	Clay	Texture	Density	Organic matter
	---- m ----	---------------- g kg^{-1}		---------------		-- g dm^{-3} --	----- g cm^{-3} -----
Native Forest	0.00-0.10	748.80	144.79	106.41	Sandy loam	1.17	21.96
	0.10-0.20	744.52	125.66	129.81	Sandy loam	1.36	11.98
	0.20-0.30	721.38	119.84	158.78	Sandy loam	1.31	9.31
	0.30-0.40	692.98	128.67	178.35	Sandy loam	1.30	7.88
	0.40-0.60	666.71	125.71	207.58	Sandy loam	1.30	7.38
	0.60-0.80	619.48	159.84	220.68	Sandy loam	1.24	6.34
	0.80-1.00	615.93	165.75	218.31	Sandy loam	1.28	4.67
Capoeira Vegetation	0.00-0.10	768.47	107.71	123.81	Sandy loam	1.23	14.84
	0.10-0.20	742.20	124.69	133.11	Sandy loam	1.44	9.90
	0.20-0.30	714.26	149.56	136.18	Sandy loam	1.34	7.69
	0.30-0.40	706.85	123.03	170.11	Sandy loam	1.34	7.10
	0.40-0.60	675.07	113.55	211.38	Sandy loam	1.35	6.29
	0.60-0.80	609.47	150.52	240.01	Sandy loam	1.33	5.40
	0.80-1.00	602.10	145.02	252.88	Sandy loam	1.48	4.60
Degraded Pasture	0.00-0.10	528.38	411.28	60.35	Sandy loam	1.40	18.19
	0.10-0.20	630.19	274.67	95.15	Sandy loam	1.47	10.28
	0.20-0.30	647.36	257.69	94.95	Sandy loam	1.49	9.05
	0.30-0.40	584.65	263.07	152.28	Sandy loam	1.58	8.14
	0.40-0.60	536.99	301.33	161.68	Sandy loam	1.48	6.84
	0.60-0.80	557.63	292.79	149.58	Sandy loam	1.59	5.21
	0.80-1.00	537.53	317.46	145.01	Sandy loam	1.51	3.64
ICLF	0.00-0.10	603.64	348.18	48.18	Sandy loam	1.32	15.98
	0.10-0.20	634.15	284.94	80.91	Sandy loam	1.39	10.65
	0.20-0.30	614.08	293.87	92.05	Sandy loam	1.38	7.76
	0.30-0.40	583.62	306.34	110.05	Sandy loam	1.46	6.43
	0.40-0.60	555.63	297.96	146.41	Sandy loam	1.53	5.00
	0.60-0.80	609.67	260.81	129.51	Sandy loam	1.53	3.60
	0.80-1.00	581.85	311.97	106.18	Sandy loam	1.53	2.78

Note. Methods: granulometry, organic matter and density (EMBRAPA, 1997).

To the depth of 1.00 m, the soil pH in the areas with native forest and ICLF were similar to each other and lower than the other areas evaluated (Table 2). In depth, there was a decrease in pH values in the degraded pasture and ICLF, ranging from 5.38 to 4.64 and 4.78 and 4.45, respectively.

Table 2. Mean values of pH and Aluminum (Al) of soils submitted to different land uses in the region of Mata dos Cocais

Depth (m)	Native Forest		Capoeira Vegetation		Degraded Pasture		ICLF	
pH								
0.00-0.10	4.83	cA	5.08	bA	5.38	aA	4.78	cA
0.10-0.20	4.73	bA	5.03	abA	5.51	aA	4.90	bA
0.20-0.30	4.66	bA	5.05	aA	5.39	aA	4.72	bAB
0.30-0.40	4.61	bA	5.03	aA	5.10	aAB	4.64	bBC
0.40-0.60	4.55	bA	5.02	aA	4.85	aBC	4.53	bC
0.60-0.80	4.59	bA	5.05	aA	4.70	aCD	4.50	bC
0.80-1.00	4.60	bA	5.11	aA	4.64	bD	4.45	bC
Al Content (cmol$_c$ dm^{-3})								
0.00-0.10	2.00	abD	0.95	aF	0.32	bDE	0.28	bD
0.10-0.20	1.02	abD	1.47	aE	0.33	bDE	0.60	abCD
0.20-0.30	1.83	aCD	2.43	aD	0.20	bE	1.05	abCD
0.30-0.40	2.58	aCD	2.95	aD	1.40	aCD	3.95	aBC
0.40-0.60	4.32	aBC	4.75	aC	4.27	aBC	6.33	aAB
0.60-0.80	9.08	aAB	7.28	aB	8.43	aAB	8.90	aAB
0.80-1.00	12.25	aA	9.57	aA	10.97	aA	10.57	aA

Note. Lowercase letters compare mean values of different uses within the same depth. Uppercase letters compare mean values of the same usage at different depths. Means followed by the same letters in the same row or column do not differ from each other based on the Bonferroni test ($\alpha = 0.05$).

In the 0.00-0.10 m layer, the exchangeable aluminum contents were lower in the ICLF system and degraded pasture in comparison to the use for poultry, with values equal to 0.32 cmolc dm^{-3} and 0.28 cmolc dm^{-3}, respectively (Table 2). In the 0.10-0.20 and 0.20-0.30 m layers, the levels of Al in the degraded pasture were inferior to those in capoeira vegetation.

In the layers 0.20-0.30, 0.30-0.40 and 0.40-0.60 m, calcium contents were higher in the degraded pasture and in the ICLF system (Table 3). These two areas also presented high levels of magnesium at depths greater than 0.40 m (Table 3). In depth, the Mg contents were similar to degraded pasture, ICLF and native forest areas. However, Ca values differed between layers in the same use, increasing with depth in all treatments.

Table 3. Mean contents of Calcium (Ca) and Magnesium (Mg) of soils submitted to different land uses in the region of Mata dos Cocais

Depth (m)	**Native Forest**		**Capoeira Vegetation**		**Degraded Pasture**		**ICLF**	
Ca Content (cmol$_c$ dm^{-3})								
0.00-0.10	2.00	aBC	1.43	aC	3.27	aA	2.70	abAB
0.10-0.20	1.83	aBC	1.17	abC	3.37	aA	2.83	aAB
0.20-0.30	1.47	aB	1.13	abB	3.23	aA	2.63	abA
0.30-0.40	1.27	abB	0.91	bcB	3.27	aA	2.43	abA
0.40-0.60	0.81	bcB	0.73	cdB	2.17	aA	2.07	bcA
0.60-0.80	0.48	cdB	0.67	cdAB	1.27	aA	1.13	cdAB
0.80-1.00	0.30	dC	0.40	dBC	0.77	aA	0.60	dAB
Mg Content (cmol$_c$ dm^{-3})								
0.00-0.10	4.17	aAB	2.97	abB	6.27	aA	6.30	aA
0.10-0.20	3.23	aA	2.67	abA	5.90	aA	6.20	aA
0.20-0.30	3.13	aA	2.41	abA	7.20	aA	6.63	aA
0.30-0.40	1.66	aB	2.09	bB	1073	aA	6.60	aA
0.40-0.60	2.63	aB	2.77	abB	7.57	aA	6.70	aA
0.60-0.80	2.92	aB	2.86	abB	7.57	aA	6.40	aA
0.80-1.00	3.57	aB	3.86	aB	6.63	aA	6.43	aA

Note. Lowercase letters compare mean values of different uses within the same depth. Uppercase letters compare mean values of the same usage at different depths. Means followed by the same letters in the same row or column do not differ from each other based on the Bonferroni test (α = 0.05).

Significantly higher levels of phosphorus were observed in the ICLF system compared to those of the native forest with babassu in the 0.00-0.10 m-layer (Table 3). In the layers 0.10-0.20, 0.20-0.30, 0.30-0.40 and 0.60-0.80 m, the contents of phosphorus in ICLP system were statistically larger than the amount found in the capoeira vegetation soil. In depth, the soils of the ICLF system showed a decrease in phosphorus levels, ranging from 10.70 mg dm^{-3} to 0.97 mg dm^{-3}.

It was observed that potassium levels in the ICLF system and in the degraded pasture were significantly higher than those of the other treatments up to 0.40 m depth, ranging from 0.92 cmolc dm^{-3} to 0.62 cmolc dm^{-3} and 1.04 cmolc dm^{-3} and 0.67 cmolc dm^{-3}, respectively (Table 4). In the different areas, except for capoeira, there were higher levels of potassium in the 0.00-0.10 m layer compared to the 0.80-1.00 m layer.

Table 4. Mean contents of exchangeable Phosphorus (P), Potassium (K) and Sodium (Na) of soils submitted to different land uses in the region of Mata dos Cocais

Depth (m)	**Native Forest**	**Capoeira Vegetation**	**Degraded Pasture**	**ICLF**
P Content (*mg* dm^{-3})				
0.00-0.10	1.26 aB	1.67 aAB	3.46 aAB	10.70 aA
0.10-0.20	1.67 aAB	0.55 aB	1.37 bAB	9.33 abA
0.20-0.30	1.67 aAB	0.74 aB	1.73 abAB	7.58 abcA
0.30-0.40	0.77 abB	0.68 aB	1.30 bA	4.72 abcA
0.40-0.60	0.97 abA	0.55 aA	1.60 abA	3.10 abcA
0.60-0.80	1.29 abAB	0.30 aB	1.48 bA	1.21 bcAB
0.80-1.00	0.27 bB	* *	1.48 abA	0.97 cA
K Content (*cmolc* dm^{-3})				
0.00-0.10	0.27 aB	0.23 bcB	1.04 aA	0.92 aA
0.10-0.20	0.25 aB	0.18 eB	0.91 abA	0.76 abA
0.20-0.30	0.26 aB	0.18 deB	0.79 abcA	0.76 abA
0.30-0.40	0.26 aB	0.21 cdB	0.67 abcA	0.62 abA
0.40-0.60	0.35 aBC	0.25 bC	0.67 abcAB	0.68 abA
0.60-0.80	0.42 aB	0.32 aC	0.50 bcB	0.66 abA
0.80-1.00	0.42 aAB	0.35 aB	0.46 cA	0.51 bA
Na Content ($cmol_c$ dm^{-3})				
0.00-0.10	0.07 aB	0.07 abcB	0.16 aA	0.15 aA
0.10-0.20	0.07 aB	0.06 bcB	0.14 aA	0.13 aA
0.20-0.30	0.07 aB	0.06 cB	0.14 aA	0.14 aA
0.30-0.40	0.07 aB	0.06 cB	0.13 aA	0.15 aA
0.40-0.60	0.07 aB	0.06 bcB	0.14 aA	0.16 aA
0.60-0.80	0.09 aBC	0.07 abC	0.13 aAB	0.15 aA
0.80-1.00	0.09 aB	0.08 aB	0.13 aAB	0.15 aA

Note. Lowercase letters compare averages between different uses within the same depth. Upper case letters compare averages within the same usage at different depths. Means followed by equal letters in the same row or column do not differ from each other by the Bonferroni test ($\alpha = 0.05$). * Values below the detection limit of the method.

The exchangeable sodium contents in the soil ranged from 0.06 cmolc dm^{-3} to 0.16 cmolc dm^{-3}, and, in the comparison between different uses, followed the same trend observed for the potassium and phosphorus contents, with significantly higher values for degraded pasture (up to the 0.60 m layer) and for the ICLF system (up to 1.00 m depth) (Table 4). In depth, similarity of sodium values was observed for all treatments, except in capoeira vegetation.

The potential acidity (H + Al) in the ICLF system and in degraded pasture was lower than the other uses in the 0.00-0.10, 0.10-0.20, 0.20-0.30 and 0.60-0.80 m layers (Table 5). In depth, there was an increase in potential acidity in all evaluated treatments, with values varying between 6.40 cmolc dm^{-3} and 20.53 cmolc dm^{-3} in soils under native forest with babassu and 2.23 cmolc dm^{-3} and 9.82 cmolc dm^{-3} in the ICLF system.

Table 5. Average values of Potential Acidity (H + Al), Sum of Bases (S), Cation Exchange Capacity (CEC) and Saturation by bases (V) of soils submitted to different land uses in the region of Mata dos Cocais

Depth (m)	**Native Forest**	**Capoeira Vegetation**	**Degraded Pasture**	**ICLF**
H + Al (*cmol*$_c$ *dm*$^{-3}$)				
0.00-0.10	6.40 cA	6.56 deA	2.56 cB	2.23 cB
0.10-0.20	6.19 cA	5.92 eA	2.23 cB	2.39 cB
0.20-0.30	6.67 cA	6.45 deA	2.48 cB	2.97 cB
0.30-0.40	6.88 cA	7.20 cdA	3.55 cA	4.37 bcA
0.40-0.60	8.53 bcA	8.21 bcA	5.20 bcA	7.34 abA
0.60-0.80	14.88 abA	12.27 abA	9.24 abB	9.65 aB
0.80-1.00	20.53 aA	14.24 aAB	10.89 aBC	9.82 aC
S (*cmol*$_c$ *dm*$^{-3}$)				
0.00-0.10	6.50 aB	0.23 bcB	1.04 aA	0.92 aA
0.10-0.20	5.38 aB	0.18 eB	0.91 abA	0.76 abA
0.20-0.30	4.94 aB	0.18 deB	0.79 abcA	0.76 abA
0.30-0.40	3.26 aB	0.21 cdB	0.67 abcA	0.62 abA
0.40-0.60	3.86 aBC	0.25 bC	0.67 abcAB	0.68 abA
0.60-0.80	4.08 aB	0.32 aC	0.50 bcB	0.66 abA
0.80-1.00	4.38 aAB	0.35 aB	0.46 cA	0.51 bA
CEC (*cmol*$_c$ *dm*$^{-3}$)				
0.00-0.10	12.75 cA	11.26 cdA	13.29 aA	12.30 bA
0.10-0.20	11.57 cA	9.99 eA	12.55 abA	12.32 bA
0.20-0.30	11.60 cA	10.23 eA	13.84 abcA	13.14 abA
0.30-0.40	10.14 cA	10.46 deA	18.35 abcA	14.17 abA
0.40-0.60	12.39 bcA	12.02 bcA	15.74 abcA	16.94 abA
0.60-0.80	18.96 abA	16.19 abA	18.71 bcA	17.99 aA
0.80-1.00	24.91 aA	18.94 aAB	18.88 cAB	17.51 abB
V (%)				
0.00-0.10	51.73 aB	41.86 aB	80.46 aA	81.86 aA
0.10-0.20	45.60 abB	40.79 aB	80.99 aA	81.26 abA
0.20-0.30	42.23 abcB	37.03 abB	81.43 aA	77.47 bcA
0.30-0.40	28.73 bcdB	31.31 bcB	80.78 aA	71.50 cdA
0.40-0.60	30.77 abcdB	31.84 bcB	68.97 abA	58.12 deA
0.60-0.80	20.80 cdB	24.29 cB	50.62 bcA	47.14 eA
0.80-1.00	17.77 dB	24.61 cB	42.91 cA	44.79 eA

Note. Lowercase letters compare averages between different uses within the same depth. Upper case letters compare averages within the same usage at different depths. Means followed by equal letters in the same row or column do not differ from each other by the Bonferroni test ($\alpha = 0.05$).

Except in depth 0.10-0.20 m, the sum of bases was statistically higher in the degraded pasture and in the ICLF system compared to the native forest with babassu and with capoeira vegetation (Table 5). There was no significant difference for the sum of bases in depth in the native vegetation area. In capoeira vegetation use, values for sum of bases varied between 4.70 cmolc dm^{-3}, in the 0.00-0.10 m layer, and 3.26 cmolc dm^{-3}, in the 0.30-0.40 m layer. In the area with degraded pasture the bases contents reached 14.80 cmolc dm^{-3}, in the layer 0.30-0.40 m and 7.99 cmolc dm^{-3}, in the layer 0.80-1.00 m. The soil of the ICLF system showed significant difference only between the 0.00-0.10 m layer and 0.80-1.00 cm, with 10.07 cmolc dm^{-3} and 7.69 cmolc dm^{-3}, respectively.

The cation exchange capacity (CEC) was similar between uses up to 0.80 m deep (Table 5). With increasing depth, there was an increase in soil CEC in almost all treatments, except in degraded pasture.

The change in land use caused differences in basal saturation between treatments for all evaluated depths. The values observed for soils under ICLF system and degraded pasture was higher than the values observed for native forest and capoeira vegetation (Table 5).

As the depth increased, there was a decrease in the base saturation value in all treatments (Table 5). However, the differences were more evident in the anthropic areas, reflecting the homogeneity of the soil under native vegetation, as had already been observed for other soil chemical parameters. In the degraded pasture, there was no variation of the base saturation up to the 0.40 m deep layer. However, in the ICLF system this behavior was only verified up to the 0.20 m layer.

4. Discussion

The pH values in all treatments and depths evaluated are considered agronomically low (Ribeiro et al., 1999). The effect of acidification of the soil in little altered areas is attributed to the lower ionic strength of the soil solution, caused by the lower contents of Ca, Mg and K (De Maria et al., 1999). Besides this, the high aluminum content observed in this study in the area with native forest also contributed to soil acidification, which through the hydrolysis of Al, releases H ions to the soil solution. In the ICLF system, there was no effect of the incorporation of 1.8 mg ha^{-1} of dolomitic limestone, 150 days after its application. These low pH values can be explained by the acidification induced by the application of the fertilizers to the soil (Graham and Haynes 2005; Lange et al., 2006). In depth, the pH results corroborate with Caires and Rosolem (1998) who used 4 mg ha^{-1} of limestone and observed an increase in pH values in the arable layer (0.00-0.20 m) and in the 0.20-0.40 m layer. This high acidity of the soil occurs parallel to the high levels of Al, very common in the Plinthsols of the region (Anjos et al., 2007).

In all soil uses evaluated, Al contents increased with depth, which may be related to the mineral complexation by the organic matter in the most superficial layer of the soil (Canellas et al., 2008). In addition, the predominance of anaerobic conditions in depth, as a function of compactness, and the process of active ferrolisis (Coelho & Torrado, 2003), releases the aluminum contained in 1:1 clay minerals, such as kaolinite (Primavesi, 1990; Anjos et al., 2007).

Siqueira Neto et al. (2009) studying the chemical attributes in different soil uses in the Brazilian Cerrado, also observed the highest average levels of calcium and magnesium in environments that underwent soil correction in comparison to the native Cerrado. However, in the results of the present study, this variation was lower, which suggests a greater influence of the source material on the availability of these elements in the soil.

According to Falleiro et al. (2003), because it is a less mobile element in the soil, calcium presents higher concentrations in the superficial layers of this environment, which can also be related to the nutrients cycling with the decomposition of the biomass in the superficial horizon. The dynamics of magnesium in soil depth evaluation, however, was different from that of calcium, especially in degraded pasture and ICLF system, a behavior similar to that found by Almeida et al. (2005) studying soils under no-tillage and conventional tillage, in an alic humic Cambisol, in the state of Santa Catarina.

According to Vione et al. (1996) soil available phosphorus levels depend on source material, degree of weathering and soil management. The addition of phosphorus in the formulation of planting fertilization in the ICLF system caused an accumulation of this nutrient, mainly in the superficial layers, due to the low mobility of phosphorus in the soil (Santos et al., 2010). Peneireiro (1999) suggests that the agrosilvopastoral system provides high levels of phosphorus resulting from tree pruning, stimulates nutrient uptake by roots and increased soil biota activity. In the native forest with babassu and capoeira vegetation, low levels of phosphorus can be related to the material that originates the Plintosols, which are predominantly formed by clayey minerals, kaolinite, hematite, goethite, muscovite and weathered biotite (Anjos et al., 2007), which may contribute to the fixation of phosphate ions.

According to Ribeiro et al. (1999), the potassium values in all sampled soils can be classified as good (between 0.18 and 0.31 cmolc dm^{-3}) or very good (> 0.31 cmolc dm^{-3}). It is important to note the similarity between soil potassium values for degraded pasture and ICLF uses, which can be caused by the high mobility of this element in this environment and/or suggest a low level of degradation of the soil under pasture.

In relation to CEC, the similarity in the distribution of chemical attributes in the soil profile may be related to uniform texture in depth, which facilitated its migration in a predominantly sandy soil. The high values of base saturation were related to correction of soil fertility by application of lime and fertilization practices, which together provide calcium, magnesium and potassium, besides neutralizing aluminum (Sousa & Lobato, 2004), which is characterized as the main component of the potential soil acidity sampled in this work. In general, in the

ICLF system and in the degraded pasture, the saturation values per base are above of the recommendation made by Ribeiro et al. (1999) which is equal to 45% for the forage grass *Urochloa brizantha* cv. Marandu.

The succession of the degraded pasture to the ICLF system in the first year did not show any differences between these uses for most of the assessed attributes, with no influence of mechanized cleaning, desiccation and fertilization to conduct the crops between these two areas. Although, with these results, growers did not perceive a significant difference in nutrient levels in the soil after harvesting corn in the ICLF system in comparison to degraded pasture. It is worth mentioning that the corn crop yield in the ICLF system exceeded 8 mg ha^{-1}, much higher than the Maranhão state average, with a mean of 3.34 mg ha^{-1} (IBGE, 2017). For the rural producer it is advantageous to produce in the ILPF system, not only for the greater productivity, but also for the diversification of income over the years and for the environmental benefits that the system promotes.

After this stage of the experiment, it is necessary to analyze the soil samples of this chrono sequence of pasture after the second year of corn harvest, to verify possible variations in fertility left by residual fertilization in the soil under corn, pasture and forest component.

5. Conclusion

Soil chemical attributes are significantly affected by land use. In general, the highest values are found in areas with degraded pasture and ICLF indicating their relative higher fertilities. In depth, the superficial incorporation of lime and fertilizer results in a decrease in pH, Ca, P, K, V%, sum of bases and increase of Al, H+Al and CEC contents. However, these effects are not evident in Na and Mg contents.

Acknowledgements

The authors thank to the Foundation for Supporting Research and Scientific and Technological Development of Maranhão (FAPEMA) for funding the Project, through the Universal Call for Research Support 14/2015. In addition, we thank for the provision of scientific initiation grants during the years of project development.

We also thank to the Brazilian Agricultural Research Corporation (EMBRAPA), for the technical and operational contribution during the research development.

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