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Original paper

Chemical attributes of an Ultisol under different management systems in a humid tropical climate

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Abstract

Agricultural use of land normally changes soil properties, depending on soil management and climatic conditions. Aiming to analyze the chemical modifications of an Ultisol, this study was conducted to evaluate the soil chemical attributes when submitted to cassava planting and fallow condition and how it compares to the natural ecosystem in the region (Atlantic Forest). Soil samples were collected at depths of 0-0.20 and 0.20-0.40 m for chemical analysis of soil characterization. Most of the chemical attributes did not differ between the systems at any depth, with the exception of K^+ in the cassava system with contents of 0.72 $cmol_c$ kg^{-1} at the depth of 0-0.20 m and 0.57 $cmol_c$ kg^{-1} at the depth of 0.20-0.40 m. The Atlantic Forest showed the highest values of P (34.61 mg kg^{-1}) and total organic carbon (2.31 dag kg^{-1}) at the depth of 0-0.20 m, which was significantly differing from the other systems. The period of 1 year fallow adopted to recover the productive capacity of the soil was not sufficient for the studied area. With the removal of the forests for implantation of the agricultural system (cassava) there was a marked reduction in the levels of organic carbon and phosphorus in the soil at the depth of 0-0.20 m.

Key-words: Agricultural Land Use, Fallow Land, Cassava, Atlantic Forest

Introduction

Agricultural land use normally changes soil properties, depending on edaphic and climatic factors. Thus, different management systems result in changes in the composition and arrangement of soil constituents, which may in some cases impact the conservation of this natural resource and reduce crop productivity (Reinert, 1998). According to Silva and Mielniczuk (1997), intensive land use with inadequate cropping systems contributes to degradation of the physical, chemical and biological properties of the soil.

Since these changes have remarkable effects on the soil properties dynamics (Biro et al., 2013), changing from forest cover to cultivated land may reduce the input of organic residues that lead to a decline in soil fertility (Muñoz-Rojas et al., 2015), loss of soil organic matter and nutrients (Saha and Kukal, 2015), acceleration of the rate of soil degradation (Barua and Haque, 2011) and increases the rates of erosion (Biro et al., 2013). The expansion of cultivated areas can substantially affect soil nutrient content by reducing the composition of plant species, net primary productivity, above and belowground allocation in plants, and nutrient cycling (Biro et al., 2013). Soil organic matter is less abundant in extremely degraded areas where overgrazing is manifest. Saha and Kukal (2015)

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found out that grassland and forests soil have higher bulk density and lower macroporosity and water retention than cultivated soil. This indicated that the conversion of natural ecosystems to agricultural systems promotes degradation of soil properties.

Understanding and quantifying the impact of different management systems on the physical, chemical and biological properties of a soil are of fundamental importance for the conservation of this natural resource, since the changes resulting from the transition to these systems are usually compared to a soil under forest systems, where the removal of an original vegetation cover and the implantation of crops associated with inadequate management practices, promotes an imbalance between soil and environment, which modifies its properties (physical, chemical and biological), and thus limits its agricultural use and makes it more susceptible to erosion (Mielniczuk, 1999).

Fallow areas are ecological management systems that seek to reproduce the environment conditions without anthropic interference in order to maintain the biological diversity of the site, as well as its productivity, regeneration capacity, and ability to perform significant ecological, economic, and social functions without threaten other ecosystems. Thus, fallow time is essential if these objectives are to be fully attained (Altieri, 2012).

In this context, the present study aimed to evaluate the chemical changes of a soil submitted to the cassava cropping, fallow area and their relationship with a tropical forest.

Material and methods

Study Area

The study areas are located in the municipality of Sirinhaém, at 8º 35' 27" S and 35º 06' 58" W, in the middle part of the South Zone, situated in the Atlantic Forest of the state of Pernambuco, Brazil (Fig. 1). The region is characterized by hilly and mountainous reliefs, with rainfall indices ranging from 2100 - 2400 mm yearly with pseudo tropical type As' according to the classification of Köpen with average annual temperatures of 25º C.

We selected three areas with different managements systems – the first area has been covered with cassava cropping for the past 20 years with no conservation management (45% slope); the second area was in a fallow time for 1 year after crop productivity losses (30% slope); and the third is an Atlantic Forest area used as reference (38%). There is a predominance of Ultisols in all of the three studied areas. The area with cassava cropping and the fallow area had a sandy-loam-clay texture in the two studied depths (0-0.20 m and 0-0.40 m). The Atlantic Forest soil has a sandy-clay texture (Santos et al., 2013).

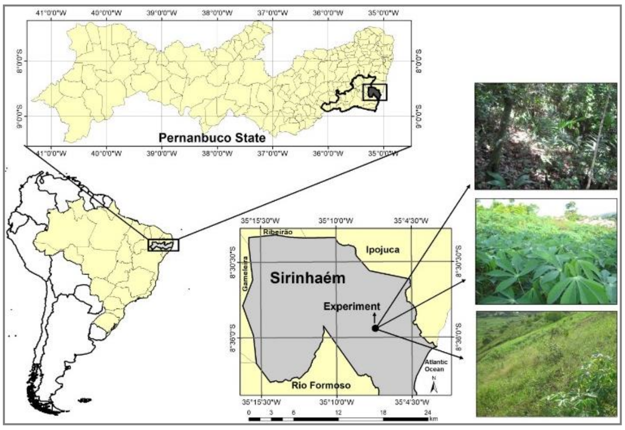

Fig. 1. Map of the study area in the municipality of Sirinhaém, state of Pernambuco.

Soil sampling

The soil samples were collected according to the methodology of systematized sampling (Meunier et al., 2002), choosing five lines of 100 m, spaced 50 m apart, perpendicular to the slope. Subsequently, 5 points were selected within each line spaced 20 m apart, forming a composite sample. The same procedure was done for each row at depths of 0 - 0.20 and 0.20 - 0.40 m, resulting in 10 samples for each system, totaling 30 samples for all systems under study.

Soil analysis

The soil pH was measured in a soil/water mixture of 1:2.5 and the exchangeable cations Ca^{2+}, Mg^{2+}, Al^{3+}, and $H^+ + Al^{3+}$ were extracted with calcium acetate solution (0,5 mol L^{-1}). The exchangeable cations K^+ and Na^+ were extracted with KCl (1 mol L^{-1}) solution and P was extracted by Mehlich 1 solution. All elements were quantified according to Embrapa (2009). The soil organic carbon content and soil organic matter content were also determined as described by Embrapa (2009). The results of these chemical analyses were used to calculate the sum of bases (SB) = $Ca^{2+} + Mg^{2+} + K^+ + Na^+$; the effective cation exchange capacity (CEC_{effect}) = CEC + Al^{3+}; the potential cation exchange capacity (CEC_{pot}) = SB + ($H^+ + Al^{3+}$); the percentage of base saturation (v) = SB/ CEC_{effect}; and the aluminum saturation percent (m) = (Al^{+3} / CEC_{effect}.) x 100.

Statistical analysis

The effects of the soil use systems on the chemical properties at each depth were verified by analysis of variance, followed by a blocking design with three treatments and five replications. Tukey's test was used at 5% for the analysis of the means. The variables values were analyzed using Shapiro-Wilk test for normality and Levene test for homocedase. SAS Learning Edition version 2.0 was used in all statistical analyzes. The variables were also subjected to a multivariate analysis with the application of factorial analysis (FA), cluster analysis (CA), and discriminant analysis (DA) in the exploratory analyzes of the specific management.

Results and discussion

Soil chemical attributes as influenced by the management system

The values of Al^{3+}, $H^+ + Al^{3+}$, Na^+, Ca^{2+}, Mg^{2+} did not show significant differences ($p > 0.05$) between the management systems in each evaluated depth (Table 1). However, significant differences for the soil pH in the cassava planting system at the depth of 0.20-0.40 m were found, with value of 3.22 differing significantly in relation to the soil under Atlantic Forest, which presented higher values of pH 4.20. According to Ribeiro et al. (1999), these systems presented high levels of Al^{3+}. The high concentration of this element is favored by the high acid levels in the soil, which increases its toxic effects in the plants. In addition, this soil may present high adsorption of anions, which may affect the efficacy of phosphate fertilizations. Soil retention of P in non-labile forms occurs by precipitation of P in solution with ionic forms of Fe or Al, and, more significantly, by the adsorption of P to the Fe and Al oxidizers. These oxidizers are generally available in larger amounts in tropical soils due to the high weathering rates (Sanchez and Uehara, 1980; Sanyal and de Datta, 1991; Valladares et al., 2003; Rolim Neto et al., 2004; Novais et al., 2007). Regarding phosphorus (P) content, significant differences between the management system with cassava planting and the fallow area at the depth of 0 - 0.20 m was observed. However, it was possible to verify significant differences in respect to the soil from Atlantic Forest, with levels of 34.61 mg kg^{-1} the highest phosphorus content. Cardozo et al. (2008) reported average P values (mg kg^{-1}) for a system of natural and fallow cultivation that are similar to the observed in this study, which was classified by the author as of low phosphorus content. According to Bayer and Mielniczuk (1997) systems that present reduced soil turnover, lead to a higher P concentration in the surface layer of the soil.

Soil potassium content reported for the state of Pernambuco by Cavalcante et al. (2008) is similar those values found in the system with cassava planting at the depth of 0 - 0.20 m (0.72 $cmol_c$ Kg^{-1}), which is considered high for the levels of this element in the soils from Pernambuco. Values of K in the cassava planting system were significantly different from fallow (0.06 $cmol_c$ kg^{-1}) and Atlantic Forest (0.12 $cmol_c$ kg^{-1}), but not at the depth of 0 - 0.20 m. At the depth of 0.20 - 0.40 m, the cassava cropping system presented the same trend at the upper depth (0 - 0.20 m), with higher potassium contents (0.52 $cmol_c$ kg^{-1}), which was significantly differing from the management the fallow and Atlantic Forest systems.

Table 2 presents the chemical attributes for the three management systems. The total soil organic carbon content (TOC) showed a significant reduction of 2.31 - 1.52 dag kg^{-1} when soil changes from native forest use (2.31 dag kg^{-1}) to agricultural use at both depths. Bayer and Mielniczuk (2008) claimed that agricultural land use changes the organic matter content and that a marked reduction is usually observed when using intensive soil tillage methods and low crop residues as in the case of planting with cassava. For the CEC_{effect}, CEC_{pot}, v, m and SB levels, no significant differences ($p < 0.05$) were observed in the change of land use for the agricultural crop and fallow area for the depths evaluated. According to Ribeiro et al. (1999), the values of CEC_{effect}, and CEC_{pot}. (Table 2) are according to high levels for the three management systems at both depths. Potential soil acidity in Atlantic Forest had an effect of increasing CEC_{effect} when compared to the other systems. Thus, when analyzing pH values and Al^{3+}, $H^+ + Al^{3+}$, CEC_{effect}, and TOC it was possible to emphasize that, possibly, the exchanges complexes are mostly occupied by Al^{3+} and H^+, disfavoring the cations bases which can be leached, impoverishing the soil, which in part is justified by the low levels of saturation of bases (v).

In a study carried out by Centurion et al. (2001), all of the analyzed soil nutrients showed the highest levels in forest, different from the result found in our study. This can be partially explained by the distinct soil conditions and forest vegetation in the

Table 1. Chemical characterization of studied Ultisol under three different management systems

Management System	pH	Al^{3+}	$H^{+}+Al^{3+}$	K^{+}	Na^{+}	Ca^{2+}	Mg^{2+}	P
		cmol$_c$ kg^{-1}						mg kg^{-1}
				0 – 0.20 m				
Atlantic Forest	3.42 A	1.68 A	7.80 A	0.12 B	0.07 A	1.26 A	0.76 A	34.61 A
Cassava	3.72 A	1.40 A	4.96 A	0.72 A	0.06 A	1.16 A	0.56 A	3.17 B
Fallow field	3.56 A	1.34 A	6.92 A	0.06 B	0.06 A	1.14 A	0.22 A	2.05 B
CV (%)	11.93	47.54	36.97	118.44	32.66	43.53	88.92	112.70
SD	± 0.42	± 0.70	± 2.42	± 0.36	± 0.021	± 0.51	±0.45	± 23.28
				0.20 – 0.40 m				
Atlantic Forest	4.20 A	1.76 A	7.11 A	0.10 B	0.08 A	1.10 A	0.56 A	4.09 A
Cassava	3.22 B	1.48 A	5.18 A	0.57 A	0.06 A	0.74 A	0.78 A	3.08 A
Fallow field	3.76 AB	1.40 A	5.78 A	0.04 B	0.05 A	1.06 A	0.48 A	0.18 A
CV (%)	16.36	32.77	33.40	121.57	52.43	40.75	69.78	169.02
SD	± 0.60	± 0.50	± 2.01	± 0.29	± 0.03	± 0.39	± 0.42	± 4.60

Identical letters in the same column did not have significant differences between the different soil management systems at the same depth by the Tukey test at 5% probability. CV: Coefficient of Variation; SD: Standard Deviation.

Table 2. Chemical attributes of studied Ultisol under three different management systems at two depths

Management System	SB	CEC_{effect}	CEC_{pot}	v	m	ESP	TOC
	$cmol_c\ kg^{-1}$			%			$dag\ kg^{-1}$
				0 – 0.20 m			
Atlantic Forest	2.22 A	3.90 A	10.02 A	24.75 A	42.37 A	1.99 A	2.31 A
Cassava	2.50 A	3.90 A	7.47 A	32.88 A	37.51 A	1.58 A	1.79 AB
Fallow field	1.48 A	2.82 A	8.40 A	17.86 A	44.81 A	2.36 A	1.52 B
CV (%)	39.51	22.67	26.60	46.08	40.10	46.94	23.98
SD	± 0.81	± 0.80	± 2.29	± 11.59	± 16.66	± 0.93	± 0.77
				0.20 – 0.40 m			
Atlantic Forest	1.84 A	3.50 A	8.95 A	21.85 A	48.95 A	2.41 A	2.17 A
Cassava	2.16 A	3.06 A	7.34 A	31.15 A	48.79 A	2.26 A	1.56 B
Fallow field	1.64 A	2.99 A	7.42 A	22.07 A	46.32 A	1.93 A	1.34 B
CV (%)	22.19	14.06	25.69	28.74	25.37	56.69	25.51
SD	± 0.41	± 0.44	± 2.03	± 7.19	± 12.18	± 1.31	± 0.43

Identical letters in the same column did not show significant differences between the different soil management systems at the same depth by the Tukey test at 5% probability. SB: Sum of bases; CEC_{effect}: effective cation exchange capacity; CEC_{pot}: Potential cation exchange capacity; V: base saturation; m: saturation by aluminum; ESP: exchangeable sodium percent; TOC: total soil organic carbon; CV: Coefficient of Variation; SD: Standard Deviation.

Table 3. Factor analysis for the chemical variables of the management systems of the study areas at depths of 0.0-0.20 and 0.20-0.40 m

Variable	0-0.20 m			0.20-0.40 m		
	F1	F2	F3	F1	F2	F3
pH	-0.341	-0.056	-0.057	0.667	0.125	0.388
Al^{3+}	0.364	0.420	**-0.715**	0.394	**-0.814**	0.105
H + Al	0.478	0.685	-0.338	-0.275	**0.858**	-0.131
K^{+}	**-0.736**	-0.088	-0.104	-0.501	0.121	0.347
Na^{+}	0.064	0.233	**0.857**	-0.031	**0.929**	-0.105
Ca^{2+}	-0.596	0.050	0.018	0.603	0.251	0.114
Mg^{2+}	-0.369	0.471	0.565	-0.198	0.468	-0.499
P	0.051	0.632	0.162	**0.739**	0.145	0.194
C.O	-0.361	**0.773**	0.274	**0.833**	0.199	0.066
SB	**-0.906**	0.261	0.303	**0.787**	0.013	-0.075
CEC_{POT}	0.182	**0.816**	-0.249	**0.853**	-0.111	-0.145
CEC_{EFET}	-0.606	0.631	-0.315	**0.786**	-0.266	-0.178
v	**-0.912**	-0.111	0.355	-0.698	0.553	0.061
m	0.629	0.095	-0.673	-0.017	**-0.903**	0.252
ESP	0.438	-0.173	**0.826**	-0.198	**0.932**	-0.036
Eigenvalue	5.00	3.33	2.38	5.05	3.22	2.24
% Total variance	33.33	22.20	15.88	33.64	21.50	14.92
Cumulative eigenvalue	5.00	8.33	10.71	5.05	8.27	10.51
Cumulative (%)	**33.33**	**55.53**	**71.41**	**33.64**	**55.14**	**70.06**

area of the present study. However, even in low fertility soils, forests do not present symptoms of nutritional deficiencies, since the nutrient cycle is practically closed, where continuous decomposition of the organic matter is observed in association with small losses by leaching. Thus, in soil under forest, the nutrient losses are lower than those under cropping systems, mainly due to the greater heterogeneity in floristic composition and better soil coverage.

Multivariate approach

Factorial analysis (FA) shows that two groups of variables were formed in three factors at both depths: a group of variables with weight in the eigenvalues, greater than 0.70; and another with weight less than 0.70 (Table 3). Thus, the chemical variables that had the lowest eigenvalue weights were discarded (according to the criteria stablished by Kaiser - eigenvalue < 0.70), because of their low contribution in the total variation of the study areas. The eigenvalue for a given component indicates how much variance it contains from the total of variances (Manly, 2008).

A second analysis including only the variables with weight higher than 0.70, showed that the three factors (1, 2 and 3) had an eigenvalue greater than 1 and an accumulated variance greater than 70% (71.41%). These factors were then selected for analysis. According to Hair Jr. et al. (2009), variables with communality below 0.5 are not sufficiently explanatory.

At the depth of 0 - 0.20 m, factor 1 (F1) grouped K^+, SB, and v; F2 grouped TOC, CEC_{pot}; and in F3 grouped Al^{3+}, Na^+, and ESP. At the depth of 0.20 - 0.40 m, F2 that grouped Al^{3+}, $H^+ + Al^{3+}$, Na^+, m, and ESP, which attribute undesirable chemical characteristics to the soil. Thus, it was shown that multivariate analysis through factor analysis is a suitable technique for exploration and reduction of a set of variables that may contribute to a better explanation of the effect of different management systems on soil chemical properties.

Figure 3 present the dendograms of the management systems at depths of 0 - 0.20 and 0.20 - 0.40 m, constructed with the variables of weight greater weights 0.70 in the eigenvalues of the factors obtained by the factorial analysis. At the depth of 0 - 0.20 m, 4 groups were formed according to the cut in the Euclidean distance and; at the depth of 0.20 - 0.40 m, 3 groups were formed. In both dendrograms, the management systems were dispersed to other groups. However, within G1 and G3, in the depth of 0 - 0.20 m, there are respectively the grouping of the Atlantic Forest system and planting with cassava in individuals groups, with homogeneous characteristics between them and, heterogeneous in relation to groups 2 and 4. The dendrogram for the depth of 0.20 - 0.40 m didn’t show the presence of isolated groups for the same management system.

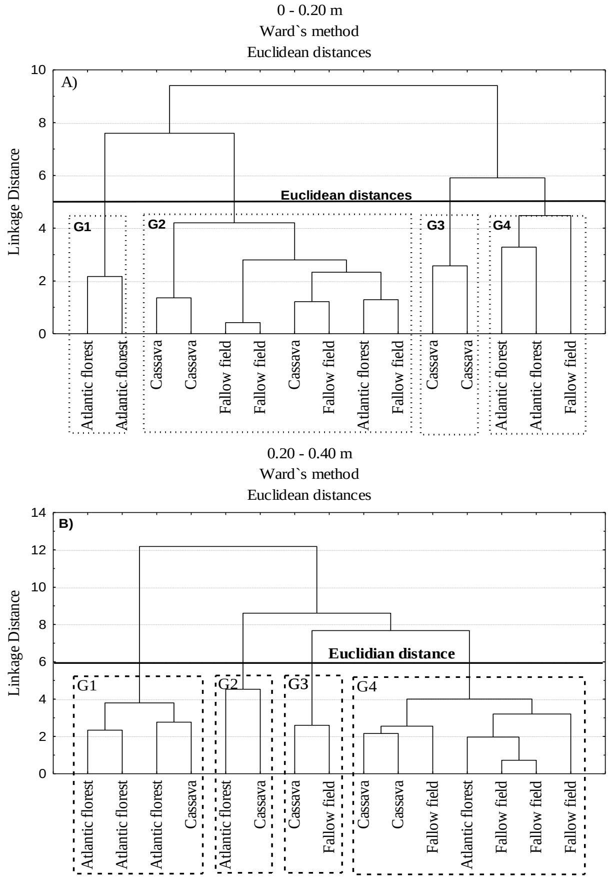

Fig. 2. Dendrogram indicating the groups formed by the management systems at the depths of 0 - 0.20 m and 0.20 - 0.40 m as function of the chemical variables selected in the factorial analysis.

Cluster analysis has been used to identify discriminations of management effects on soil properties (Sena et al., 2002; Mico´ et al., 2008). In the present study, it was observed the formation of a group isolatively from the other management systems, confirming the result of the cluster analysis (CA) where all the systems present in the CA groups were correctly grouped with a percentage of 100% accuracy for both depths (Fig. 3a and 3b). Soils were clustered into four groups corresponding to the land-uses (Fig. 2), indicating that the soils were highly different regarding chemical composition. It has been reported that agricultural management poses remarkable impacts on the distribution of C (Zhang et al., 2006), N (Cookson et al., 2007) and P (Castillo and Wright, 2008b).

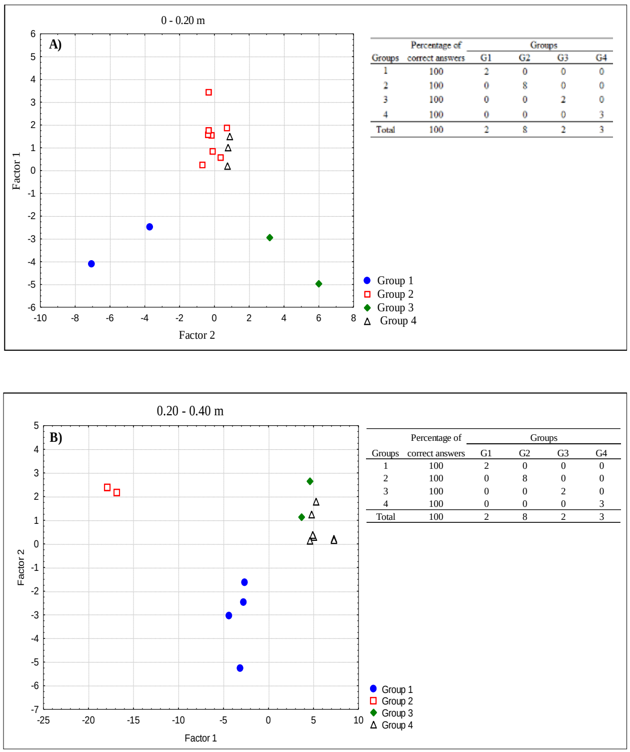

Fig. 3. Discriminant analysis for the management systems at the depths of 0 - 0.20 m (a) and 0.20-0.40 m (b) as a function of cluster analysis.

Conclusion

The 1 year period in the fallow area for the recovering of natural fertility and soil productive capacity was not sufficient to increase the attributes content of the evaluated soil and the withdrawal of forests to the implantation of agricultural systems caused a marked reduction of most of the soil chemical attributes.

The use of the multivariate technique in data in the different management systems was satisfactory, since it showed coherence in the heterogeneity of the different management systems, as verified by the formation of non homogeneous groups of management systems by the cluster analysis with a percentage of correctness of 100% at both depths.

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