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ATTRIBUTES OF PEDOINDICATOR SOILS IN AREAS CULTIVATED WITH TYPICAL CROPS IN THE WESTERN AMAZON, BRAZIL

ATRIBUTOS DE SOLOS PEDOINDICADORES EM AREAS CULTIVADAS COM CULTURAS TÍPICAS NA AMAZÔNIA OCIDENTAL, BRASIL

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ABSTRACT: The crop systems adopted in the Amazônia region have been studied several times in terms of the variability and to indicate the soil attributes more sensitive to the different crops. Thus, the objective of this work was to apply multivariate techniques in order to identify the chemical attributes most sensitive to environmental changes in different crop systems in Western Amazonia, Brazil. The research was conducted in five rural properties located in the Humaitá city region, Western Amazonia, Brazil. There were selected four environments with natural characteristics (Native Forest - NF) and five cropping systems (Grazing, Cassava, Açaí, Agroforestry and Reforestation). In the selected areas, soil samples were collected at depths layers of 0.0-0.05 m; 0.05-0.1 m and 0.1-0.2 m and the following chemical analyzes were performed: pH in water, Ca^{2+}, Mg^{2+}, K^{+}, Resin-P, phosphorus bio-available particulate (Pbp), OC, Al^{3+}, $H^{+}+Al^{3+}$ and from these results SB, T, t, m% and V% were calculated. Multivariate statistical techniques were used to verify similarities between the crop systems in the attempt to relate the crops grown and the chemical attributes. The multivariate analysis was essential in the crop systems distinction, as well as to describe the relationship with the chemical properties. The results demonstrate and reinforce the existing variability between crop systems, with emphasis on the variation in crop systems, compared to natural environments.

KEYWORDS: Chemical attributes. Multivariate techniques. Native forest. Soil attributes.

INTRODUCTION

The typical crops cultivated in the Western Amazônia have been studied in terms of the variability exercised by land management rudimentary practices, as well as to indicate the soil attributes more sensitive to the different crops, in order to discover it is influence on soil fertility (OLIVEIRA et al., 2013; AQUINO et al., 2014; MANTOVANELLI et al., 2015). In this regard, Mantovanelli et al. (2016), studying the chemical attributes that indicate soil acidity found that [illegible] extremely sensitive when evaluated in environments without direct anthropogenic influence. However, Oliveira et al. (2015) studying soil attributes under different land uses in the Southern Amazonas region, found that the chemical attributes under different managements practices are homogeneous and there was practically no difference between the areas according to attributes studied.

That said, the knowledge of the chemical modifications of the soil, caused by continuous cultivation, provides subsidies for the adoption of management practices that allow to increase the crop yield, secureing the continuous sustainability and conservation of ecosystems (FREITAS et al., 2015). Therefore, assessments of changes in soil properties resulting from the impacts of human intervention on natural ecosystems can be an important tool to assist in monitoring conservation of these environments.

In this context, in order to have a better visualization of the behavior of soil chemical attributes regarding anthropic intervention, multivariate statistical analysis techniques are [illegible] this function, since through these techniques it is possible to correlate soil attributes to the management adopted. These techniques include main component analysis (MCA), which aims to reduce the dimensional problem and promote data interpretation. This factor analysis is a statistical technique that aims to describe the variables set structure dependency and measure common points (BARROSO; ARTES, 2003).

Following the study line, studies with using multivariate methods were applied to the chemical attributes of soils in the Amazonian

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environments, aiming to determine the variability caused by the practices and crop systems. In this sense, Oliveira et al. (2015) defined that chemical attributes, pH, potential acidity, organic matter, phosphorus, potassium, calcium and magnesium, were the most sensitive to distinguish managements in Agroforestry, Cassava and Sugarcane systems. In turn, Mantovanelli et al. (2015), applying multivariate techniques, found that chemical attributes, pH, potential acidity, exchangeable aluminum, organic carbon and soil carbon stock, were responsible for the distinction of three management systems, being them, native field area, cultivated and degraded area.

The combined use of the multivariate techniques based on soil attribute´s patterns are effective for decision making about land usage and management, and potential indicators of major changes due to human interference (OLIVEIRA et al., 2017). The association of multivariate methods with the ternary diagrams is a powerful tool for statistical quality control, and as indicative of how the chemical variables are affected in each crop system.

Thus, the objective of this study was to investigate the correlation between soil chemical attributes and different crop systems adopted in Western Amazonia, by means of multivariate techniques, and thus identify which attributes may be indicators of alteration of these studied environments.

MATERIAL AND METHODS

Description of studied areas

The study was conducted in five rural properties located in Western Amazônia, precisely in Humaitá City, on Southern region of Amazonas state (Figure 1). According to Köppen classification, the climate is classified as Humid Tropical, with a short dry period (Am), the amount of annual rainfall is between 2,250 and 2,750 mm (concentrated from October to June of the following year), relative humidity between 85 and 90% and temperatures varying between 25 and 27°C (BRASIL, 1978). Four environments with natural characteristics (Native Forest - NF) were selected as testimony of areas without anthropic changes. In the same farm areas, five Amazonian crop systems were selected: Grazing, Agroforestry, Cassava, Açaí and Reforestation, whose respective historical usage are presented in Table 1.

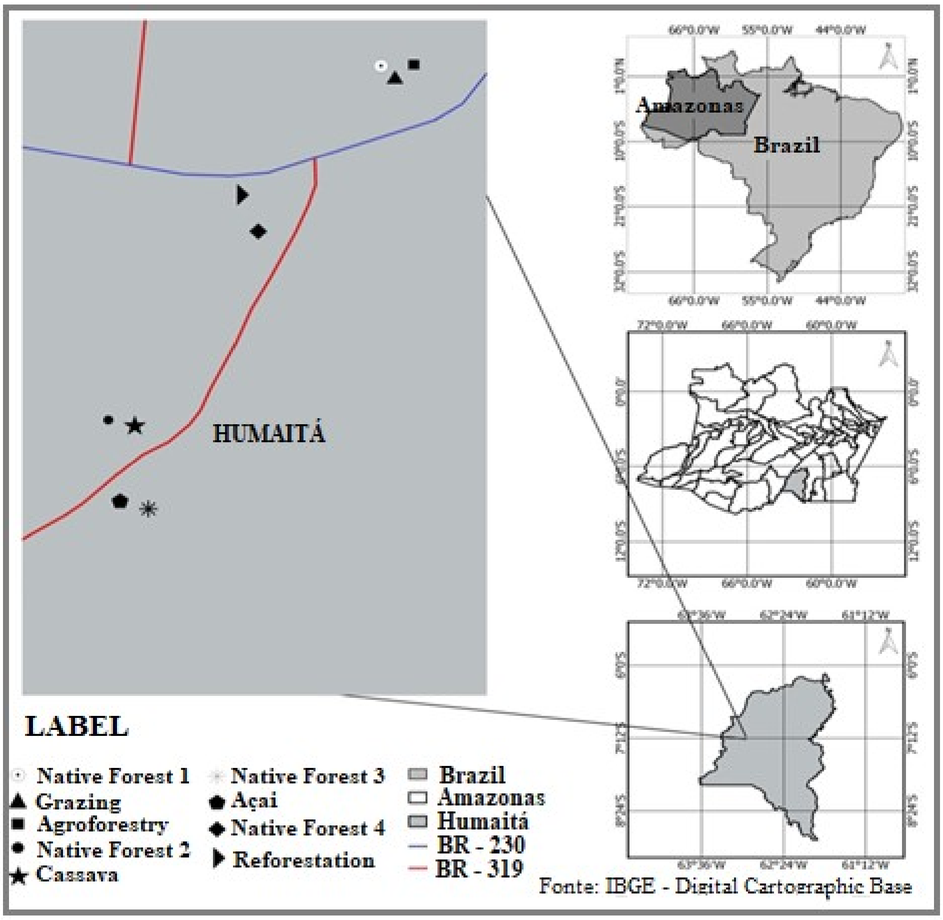

Figure 1. Study area location and crop systems in Humaitá City.

Table 1. Selected areas and historical of crop system in Humaitá City, South Amazonas region, Brazil.

Crop system	Location	Crop history	Soil class*
Grazing	7º27'23"S; 63º02'26" W, 62 m of elevation.	*Brachiaria brizantha* (cv. Marandu) with Tucumã (*Astrocaryum aculeatum*) palm trees scattered over the pasture; more than 20 years of implantation; cattle grazing at low stocking density	Typic Haplohumult
Agroforestry	7º27'24"S; 63º02'15" W, 62 m of elevation.	About 15 years of age, with species such as Andiroba (*Carapa guianensis*), Cupuaçu (*Theobroma grandiflorum*), Açaí (*Euterpe oleracea)*, Brazilian-nut (*Bertholletia excelsa*), Jenipapo (*Genipa americana* L.), Cocoa *Theobroma cacao*), Pupunha (*Bactris gasipaes*) and Tucumã (*Astrocaryum aculeatum*).	Typic Haplohumult
Cassava	7º47'40"S; 63º10'23" W, 70 m of elevation.	Successively growing crops for 10 years using disking tillage before each planting	Typic Hapludox
Açaí	7º48'55"S; 63º11'08" W, 70 m of elevation.	Started in 2010, with irrigation system and fertilization.	Typic Kandiudox
Reforestation	7º34'45"S; 63º06'54" W, 65 m of elevation	Implemented in 2004, with Teca (*Tectona grandis L.*), Mogno (*Swietenia macrophylla King.*), Andiroba (*Carapa guianensis Aubl.*), and Jenipapo (*Genipa americana L.*).	Typic Fluvaquents

* Soil Taxonomy (SOIL SURVEY STAFF, 2014) and SiBCS (SANTOS et al., 2018)

Field and laboratory methods

The soil samples were taken at depths of 0.0-0.05 m; 0.05-0.1 m e 0.1-0.2 m, in randomized and equidistant points on the crop fields, totalizing 108 disturbed single samples. The sampling points coordinates were recorded with a Global Position System (GPS) tool, Garmin brand (GPSmap 64S).

The pH in water was determined by potentiometric measurement using a 1:2.5 ratio of soil in a solution of water and KCl (EMBRAPA, 2017). Calcium, magnesium and exchangeable aluminum were extracted by a KCl solution (1 mol L^{-1} concentration) and the potential acidity (H+Al) was extracted with buffered calcium acetate solution at pH 7.0 (EMBRAPA, 2017). Potassium was extracted with Mehlich^{-1} solution, using a method proposed by Embrapa (2017) .

The phosphorus bio-available particulate (Pbp) was determined by anion exchange resin extraction (AER). The phosphorus extraction principle by AER is its continuous solution removal by the exchange with the resin bicarbonate, creating a concentration gradient that forces the colloids surface exit, up to an electrochemical equilibrium is reached between the soil and the AER (SKOGLEY; DOBERMANN, 1996). Based on the methodology developed by Kroth (1998) and briefly described here: 0.5 g of soil (1 mm) was added in 15 mL Falcon conical tubes containing 10 mL of distilled water and a saturated AER sheet with 0.5 mol L^{-1} of $NaHCO^3$. The tubes were shaken for 16 hours on an "end-over-end" stirrer (33 rpm). The sheets were removed and washed with jets of distilled water and then diluted in 10 mL solution of 0.5 mol L^{-1} HCl. The tubes remained uncapped for 90 minutes and then closed and shaken for 30 minutes (horizontal stirrer). Then, a 3 mL aliquot was taken from the extract to determine the P content according to Murphy and Riley (1962). The organic carbon was determined by the wet oxidation method, with external heating (YEOMANS; BREMNER, 1988). Based on the results of the chemical analyzes, the sum of bases (SB), potential CEC (T), effective CEC (t), base saturation (V%) and aluminum saturation (m%) were calculated.

A eigenvalues "scree-plot" was created to determine the number of components to be excluded. This chart sorts the eigenvalues according to the major components, plotting the variance percentage for each attribute. Notably, this component analysis should explain more than 70% of the total variance (HAIR et al., 2005), thus constituting the response variables chosen for principal component analysis (PCA).

Subsequently, the factor analysis was performed, which allowed the relations between the variables to be explained as new variables limited number, extracting the main components calculated from the correlation matrix between the variables. All statistical analyzes were performed using Statistica software 7.0 version (STATSOFT, 2004)

Pearson´s correlation analyzes were performed, and for the chemical variables that presented high correlation, the ternary diagrams were generated as a criterion to analyze the presence of variability among the crop managements.

RESULTS AND DISCUSSION

The accumulated variability relation of the chemical attributes studied in the different crop systems explained between 59% and 72% of the extractable variance in the different depths evaluated (Table 2 and Fig 2). According to Hair et al. (2005), 70% accumulation of the total variance can explain the soil attributes discriminant power and each variable contribution in the total variance. So, the 0.1-0.2 m depth layer, of the soils in the crop systems studied may not represent the chemical properties.

Table 2. Chemical attributes main components contribution on crop systems in the Southern Amazonas.

Variables	0.0-0.05 m		0.05-0.10 m		0.10-0.20 m	
	PC1	PC2	PC1	PC2	PC1	PC2
pH in water	10.09	1.10	10.30	0.05	9.88	1.70
Resin-P	0.14	17.98	0.91	17.33	0.26	12.38
OC	2.85	7.94	0.01	9.18	1.49	7.35
Al^{3+}	11.03	0.001	12.33	0.003	11.97	0.96
H+Al	4.69	22.02	0.26	29.14	2.88	27.86
K^{+}	3.53	9.64	7.94	3.54	4.59	2.58
Ca^{2+}	12.05	1.23	11.08	0.75	7.93	0.11
Mg^{2+}	12.22	2.97	12.16	0.97	8.77	5.07
SB	12.56	2.20	13.69	0.03	12.41	1.97
T	1.18	33.06	0.04	29.12	1.39	29.67
t	3.82	1.29	8.13	0.02	7.38	0.43
V %	12.38	0.18	8.35	9.81	13.43	8.08
m %	13.43	0.33	14.73	0.01	17.58	1.78
% Cumulative variability	70.12		72.47		59.81	

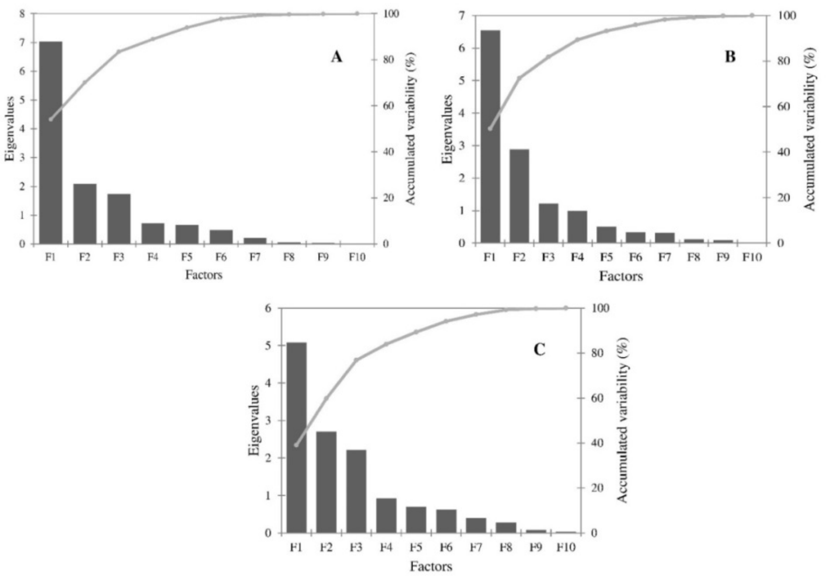

Figure 2. Data set variation relationship explained by the Principal Component (PC) and contribution of each variable in the total variance by "scree plot".

According to the variability pattern of the main components, the 0.0-0.05 m layer depth corresponded to 70% of the accumulated variability in the principal components 1 and 2; especially for the attributes T (34%), H + Al (26 %) and Resin-P (18%). The 0.05-0.1 m layer showed an accumulation of 72%, T (29%), H + Al (29%) and Resin-P (18%); and in the 0.1-0.2 m layer showed T (30%), H+Al (29%) and Resin-P (13%) as shown in Table 2. Oliveira et al. (2017) studying chemical attributes in crop systems in the Southern Amazonas, found accumulated variability between 83% for the 0.0-0.10 m layer and 74% for 0.10-0.20 m layer, corroborating the variability effect reduction on depth.

The eigenvalues "scree plot" (Figure 2) confirm that the first and second major components were required to explain the total variance, since they have high values (7.01 and 1.08 at 0.0-0.05 m depth; 6.87 and 1.06 at 0.05-0.1 m depth; 5.21 and 1.00 at 0.1-0.2 m depth), justifying the use of principal component analysis 1 (PC1) and principal component analysis 2 (PC2) (KAISER, 1958).

After choosing the number of factors to be used, we proceeded to obtain the factorial loads and the factor rotation. Thus, for the situation of the present study, factors 1 and 2 were the ones that presented the highest corresponding loads (Table 3).

Moreover, it is observed that in the depths evaluated for the different crop systems studied, there was a significant difference for factor loads. In the 0.0-0.05 m and 0.0 - 0.1 m depth layers, factors 1 and 2 showed the highest values for pH, Resin-P, Al^{3+}, H+Al, K^+, Ca^{2+}, Mg^+, SB, t, V% m%, denoted as the factors that describe the nutrients availability. Frade et al. (2015), studying physicochemical attributes by multivariate methods, found similar results, emphasizing the effect of variables more related to the chemistry of soil colloids, showing a direct relation with the variables described above from the factorial loads.

Under the conditions of the present study, Organic Carbon (CO) was not considered a corresponding chemical variable that directly contributed to the differentiations between the cultivation systems. In the cultivation systems of the Amazon, the loss of organic matter (OM), associated with soil degradation, mainly compaction and an accelerated weathering process, favors the low input of OM and, consequently, a reduction in CO levels. In this context, due to the low supply of OM in grazing, cultivation of cassava and açaí, it is implied that this is a factor that contributed to the condition of non-contribution of the CO variable in the factorial loads. Mantovanelli et al. (2015) Mantovanelli et al. (2015) studying the effect of management practices on soil attributes, found an inverse relationship between CO and crop management that depletes soil nutrients, so such practices should be monitored as a criterion for maintaining CO.

Table 3. Factorial loads extracted by main components, emphasizing soil chemical variables with loads higher than 0.7 on traditional cropping systems in the Southern Amazonas.

Variables	0.0-0.05 m		0.05-0.10 m		0.10-0.20 m	
	PC1	PC2	PC1	PC2	PC1	PC2
pH in water	**-0.84***	0.152	**-0.82***	0.03	**-0.70***	0.21
Resin-P	0.10	0.613	-0.24	**0.70***	0.11	0.57
CO	0.44	0.407	0.03	0.51	0.27	0.44
Al^{3+}	**0.88***	-0.004	**0.89***	0.009	**0.78***	-0.16
H+Al	0.57	0.678	0.13	**0.91***	0.38	**0.86***
K^+	-0.49	0.449	**-0.72***	0.32	-0.48	0.26
Ca^{2+}	**-0.92***	0.16	**-0.85***	-0.14	-0.63	0.05
Mg^{2+}	**-0.92***	0.24	**-0.89***	0.16	-0.66	0.37
SB	**-0.94***	0.21	**-0.94***	0.03	**-0.79***	0.23
T	0.28	**0.83***	-0.05	**0.91***	0.26	**0.89***
T	0.51	0.16	**0.72***	0.02	0.61	-0.10
V %	**-0.93***	-0.06	**-0.73***	-0.53	**-0.82***	-0.46
m %	**0.97***	-0.08	**0.98***	-0.01	**0.94***	-0.22

OC = organic carbon; $Al3^+$ = exchangeable aluminum; H+Al = potential acidity; SB = sum of bases; T = potential CEC; t = effective CEC; V% = base saturation; m% = aluminum saturation. * = significant

The chemical variables that discriminated best the groups of crop systems were characterized by the biplot representation (between PC1 and PC2) in the Figure 3. In this condition, it was observed that the evaluated depths layers showed different relationship patterns according to the systems studied, indicating initially a wide variability in soil profile of these environments. Freitas et al. (2014); Freitas et al. (2015); Oliveira et al. (2015); Mantovanelli et al. (2015) found different association patterns between groups of variables associated to the crop systems and managements adopted in reforestation, native forest and sugarcane areas, indicating that despite the similarity in the parent material, the crop management influenced the soil chemicals attributes.

In Figures 3A and 3B which correspond to the 0.0-0.05 and 0.05-0.1 m layers, respectively, it was observed two specific groups formation. Group I the NF1, NF2, NF3, NF4, Grazing and Agroforestry, which are related to the chemical variables H+Al, Al^{3+}, m%, OC and Resin-P and group II formed by Açaí, Cassava and Reforestation with direct relation to the variables of $K^{+,}$ Ca^{2+}, Mg^{2+}, SB, V% and pH in water.

The low chemical indexes in the studied native forest soils may be the result of the intense cycling of nutrients through the forest. In addition, the base leaching promoted by the intense water regime in the region, associated with the absence of correctives practices, contributes to the reduction of nutritional values on natural systems (CAMPOS et al., 2012). This condition was also verified by Freitas et al. (2014), which associated factor scores and contribution weight of the studied variables.

The greater relationship of the native forest and OC is a consequence of the absence of anthropic intervention, that is, without the use of agricultural implements and cultural treatments, not degrading the stability of soil aggregates (MORAIS; PISSARRA; REIS, 2012; FREITAS et al., 2014).

As observed in Figures 3A, 3B and 3C, the grazing system has always been directly related to the OC content, this is due to the fact that the grazing offers a permanent coverage and a high root distribution, so the decomposition of this vegetal material contributes to the gradual increase of OC (CARNEIRO et al., 2009).

The relationship effects of Al^{+3}, H+Al and m% in native environments is a striking feature of the soils of these ecosystems, a fact that is associated with the MO content in the soil, since it has several functional groups, especially carboxylic and phenolic groups, which can release the H that will compose the ions involved in the capacity of soil cation exchange, causing its acidification (SOUSA; MIRANDA; OLIVEIRA, 2007; FREITAS et al., 2014). This condition is evident in Figure 3C that the NF2 presents direct relationships with soil exchangeable bases, indicating the differentiated pattern among the native forests studied.

The high Al^{3+} levels are predicted in soils under native vegetation that supports plants highly adapted to Al^{3+} toxic effect (SOARES et al., 2011). As observed for pH variations, the Al^{3+} contents were lower in the crop systems due to liming. Studying the exchangeable acidity (Al^{3+}) effect in the native fields, Mantovanelli et al. (2016) also found the aluminum toxic effect and greater association, evidencing the greater complexation of this element in Amazonian environments due to weathering process. In grazing and agroforestry systems, the relationship with the soil acidity components is also observed, indicating the crop managements practices wear effects as a degradation function, applied to the soils greater capacity and use exploration.

In the reforestation system (Figure 3A and 3B) were observed values inverse to the others, in which there was a greater relation of the system with the exchangeable bases, thus strengthening the fact that this environment is in the recovery stage of its chemical properties. It is observed a great approximation with the environments with Açaí and Cassava, justifying that the alterations of its attributes are due to the soil management. Similar results were observed by Braz, Fernandes and Alleoni (2013); Freitas et al. (2015), when studying native forest changes and different soil systems, observing the main effect on the exchangeable bases Ca^{2+}, Mg^{2+} and K^{+}. The environments with Açaí and Cassava, although being grow with low mineral fertilizer load, were related to fertilization elements such as Ca^{2+}, Mg^{2+} and pH in water, explained by the continuous liming and inputs that contributed to higher base results, evidencing as well as those most sensitive to such modifications.

The highest distinction between the treatments studied can be observed from Fig 3C, in which three groups were formed, Group I being composed by Grazing, with relation to OC and Resin-P; Group II formed by NF1, NF3, NF4 and Agroforestry attributed to t, Al^{3+} and m%; and Group III composed of NF2, Açaí, Reforestation and Cassava with relation to Ca^{2+}, Mg^{2+}, K^{+}, SB, pH and V%. From these evidences, it is clarified that the 0.1-0.2 m depth layer is more propitious to not characterize the variations resulted by the management practices in the soil chemical properties, because the greater groups distinction with a smaller variable set is the variability observed by the factorial loads (HAIR et al., 2005).

Studies developed by Freitas et al. (2015) and Oliveira et al. (2015) observed that in deeper layers between 0.2-0.6 m there is a greater management groups separation, showing to be not necessary a possible evaluation of these layers in soil fertility monitoring programs, from natural environments converted to crop systems.

Table 4 shows Pearson's correlation of chemical attributes. Regarding m% and Al^{3+}, there was a correlation with all pairs, with the exception of m% x Resin-P (0.076), m% x T (0.156), Al^{3+} x Resin-P (0.245) and Al^{3+} x T (0.108). The pH in water did not correlate with Resin-P (-0.061), OC (-0.188) and T (-0.161), however these inverse correlations are admitted as very low and insignificant to changes in these properties as a function of pH in water. The Pearson´s correlation showed to be necessary to monitor Al^{3+} and m% in the Amazon farming systems and their respective levels in natural environments. Following a general cropping systems group and chemical attributes, it is observed the inverse influence of these elements on the soil, especially when it is related to the exchangeable bases (Ca^{2+}, Mg^{2+} and K^{+}).

The high degree of m% and Al^{3+} is not restricted only to the arable layer, but in some soils, it also occurs in depth. The plants root system is poorly developed, restricting itself to the region in which liming and fertilizer were added, limiting the water and nutrients absorption from layers below the arable layer. As observed in the MCA (Figure 3), the ratio of Al^{3+} and m% was always related to native forests, evidencing that in the crop systems, the small chemical fertilizers additions promote the nutrients cycling, improving the chemical conditions of the soil in the arable layer. It is worth noting that the relationship of Al^{3+} and m% with native forests, is not necessarily a bad condition, because in these environments there is the natural process of nutrient cycling, so does not require the addition of fertilizers.

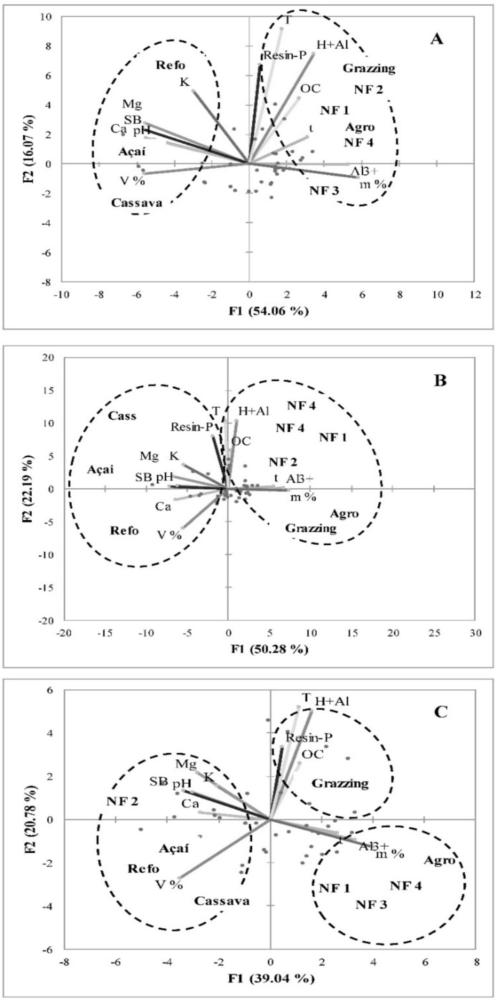

Figure 3. Soil chemical attributes main components analysis.
A = 0.0-0.05 m depth layer; B = 0.05-0.1 m depth layer; C = 0.1-0.2 m depth layer.

Table 4. Pearson´s correlation of soil chemical attributes under traditional crop systems of Southern Amazon.

Variables	pH in water	Resin-P	OC	Al^{3+}	H+Al	K^{+}	Ca^{2+}	Mg^{2+}	SB	T	t	V %	m %
pH in water	**1**	-0.06	-0.18	**-0.71**	**-0.40**	**0.56**	**0.75**	**0.77**	**0.78**	-0.16	**-0.40**	**0.74**	**-0.76**
Resin-P	-0.06	**1**	**0.35**	0.24	0.20	0.15	0.06	0.09	0.08	0.25	**0.41**	0.003	0.07
OC	-0.18	**0.35**	**1**	**0.46**	**0.33**	-0.16	-0.27	-0.27	-0.28	0.26	**0.43**	-0.32	**0.44**
Al^{3+}	**-0.71**	0.24	**0.46**	**1**	**0.34**	**-0.45**	**-0.71**	**-0.74**	**-0.74**	0.10	**0.84**	**-0.69**	**0.91**
H+Al	**-0.40**	0.20	**0.33**	**0.34**	**1**	-0.002	**-0.47**	**-0.39**	**-0.44**	**0.94**	0.14	**-0.68**	**0.44**
K^{+}	**0.56**	0.15	-0.16	**-0.45**	-0.002	**1**	**0.36**	**0.46**	**0.44**	0.16	-0.30	0.31	**-0.48**
Ca^{2+}	**0.75**	0.06	-0.27	**-0.71**	**-0.47**	**0.36**	**1**	**0.94**	**0.98**	-0.16	-0.23	**0.92**	**-0.89**
Mg^{2+}	**0.77**	0.09	-0.27	**-0.74**	**-0.39**	**0.46**	**0.94**	**1**	**0.98**	-0.07	-0.29	**0.91**	**-0.91**
SB	**0.78**	0.08	-0.28	**-0.74**	**-0.44**	**0.44**	**0.98**	**0.98**	**1**	-0.12	-0.27	**0.92**	**-0.91**
T	-0.16	0.25	0.26	0.10	**0.94**	0.16	-0.16	-0.07	-0.12	**1**	0.05	**-0.40**	0.15
t	**-0.40**	**0.41**	**0.43**	**0.84**	0.14	-0.30	-0.23	-0.29	-0.27	0.05	**1**	-0.26	**0.58**
V%	**0.74**	0.003	-0.32	**-0.69**	**-0.68**	0.31	**0.92**	**0.91**	**0.92**	**-0.40**	-0.26	**1**	**-0.88**
m%	**-0.76**	0.07	**0.44**	**0.91**	**0.44**	**-0.48**	**-0.89**	**-0.91**	**-0.91**	0.15	**0.58**	**-0.88**	**1**

OC = organic carbon; Al^{3+} = exchangeable aluminum; H+Al = potential acidity; SB = sum of bases; T = potential CEC; t = effective CEC; V% = base saturation; m% = aluminum saturation. Bold values = significant.

The chemical attributes variability ternary patterns (Figure 4) indicated the most representative chemical attributes evident variability, demonstrating the need to mitigate the negative effects of conversion of natural forests to crop systems. In the 0.0-0.05 m depth the variables trio OC x Resin-P x pH were analyzed, implying that the maintenance of OC favors greater surface availability of P, which the variability pattern was concentrated only between OC and pH in water. The relation Mg^{2+} x Ca^{2+} x Al^{3+} was shown to be opposing to the first condition, indicating the marked dispersion between these chemical variables.

At the 0.05-0.1 m depth the variability pattern was concentrated in the variables trio OC x Resin-P x K^{+} and OC x Resin-P x H + Al and showing only in the second relation a dispersion more evident, indicating that in subsurface, there is a greater variation of these variables. In subsurface 0.1-0.2 m pH in water and Al^{3+} monitoring is indispensable, since the variability is totally concentrated in these attributes from the variables trio's correlation, which in the root system zone is totally fragile under the present study conditions. Although these crop systems are under equal condition of the source material, they come from alluvial sediments, the variability pattern is evident among the adopted crop managements, indicating the total modification over the years by the crop systems, evidencing the sensitivity of some chemical properties to such anthropic modifications.

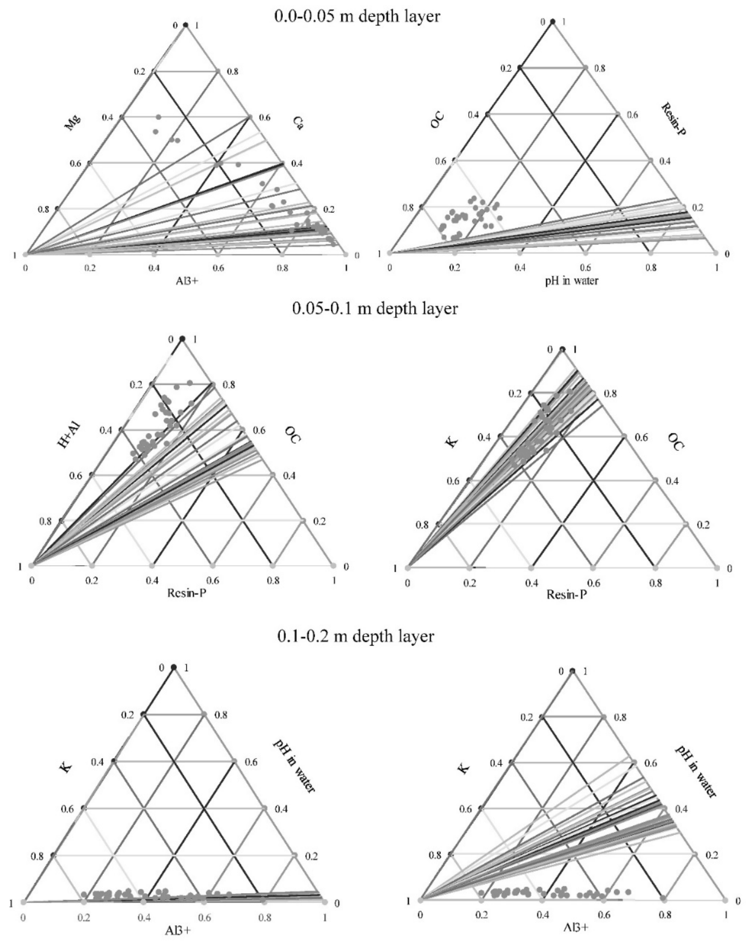

Figure 4. Variability pattern ternary diagrams of the soil chemical attributes under traditional crop systems in the southern Amazon.

CONCLUSIONS

The monitoring of CO in Amazonian crop systems should be evaluated in future studies, since the cultivation practices adopted, totally modify its dynamics, thus favoring the greater dispersion of this chemical variable.

The 0.0-0.05 m layer in Amazonian environments represents the highest degree of assessment for the fertility of these soils, especially considering crop systems with intense extraction of exchangeable cations. In subsurface 0.1-0.2 m pH monitoring in water and Al3 + is indispensable, since the variability is totally concentrated in these attributes from the correlation of the trios of variables, being that the zone of the root system of the cultures in subsurface is totally fragile in these conditions of the present study.

From the ternary variability diagrams, it was possible to relate the trio of variables that present high variability from the studied cultivation systems.

RESUMO: Os sistemas de cultivos adotados na região Amazônica vêm sendo utilizados em diversos estudos em termo da variabilidade exercida pelas práticas de manejo e até mesmo indicar aqueles atributos mais sensíveis a esses manejos. Assim, o objetivo deste trabalho foi aplicar técnicas multivariadas a fim de identificar os atributos químicos mais sensíveis às mudanças ambientais em diferentes sistemas de cultivo na Amazônia Ocidental, Brasil. A pesquisa foi realizada em cinco propriedades rurais localizadas na região de Humaitá, Amazônia Ocidental. Foram selecionados quatro ambientes com características naturais (Floresta Nativa – FN) e cinco ambientes cultivados (Pastagem, Mandioca, Açaí, Agrofloresta e Reflorestamento). As amostras de solos nas áreas selecionadas foram coletadas nas profundidades de 0,0-0,05 m; 0,05-0,1 m e 0,1-0,2 m. Foram realizadas as seguintes análises químicas: pH em água, Ca^{2+}, Mg^{2+}, K^{+}, Presina, CO, Al^{3+}, $H^{+}+Al^{3+}$ e a partir do resultado dessas análises foram calculadas a SB, T, t, m% e V%. Utilizaram-se técnicas de estatística multivariada para verificar semelhanças entre as práticas de manejo na tentativa de agrupar os sistemas de uso/atributos químicos. A análise multivariada foi preponderante na distinção dos sistemas de cultivos estudados, bem como caracterização da relação com as propriedades químicas. Os resultados demonstram e reforçam a variabilidade existente entre os sistemas de cultivo, com ênfase na variação dos sistemas de cultivo, em comparação com os ambientes naturais.

PALAVRAS CHAVE: Atributos do solo. Atributos químicos. Floresta nativa. Técnicas multivariadas.

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