



Multivariate analysis in the evaluation of soil attributes in areas under different uses in the region of Humaitá, AM

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ABSTRACT

The recognition of the influence of management practices on soil physical and chemical conditions is substantial for sustainable agriculture. For this reason, this study was developed for the purpose of evaluating the behavior of soil attributes under different uses in the region of Humaitá, AM, using multivariate statistical methods. The study was developed in 8 rural properties producing bananas, grassland, maize, coffee, cassava, vegetables, agroforestry system and a forest fragment. Samples of soils with preserved structure in the 0.0 - 0.10 and 0.10 - 0.20 m layers were randomly collected in 5 small trenches per area, totaling 32 samples in the management systems, to determine the physical and chemical attributes. The data were then submitted to univariate and multivariate statistical analysis. Exploratory data analysis (principal components and dendrogram) and frequency of environmental covariates was efficient in distinguishing production environments, so multivariate classification based on physical and chemical attributes of the soil can help in the proper planning of land use. The analysis of the principal components indicates that the BD presents direct dependence with the SPR, signaling the use of the soil with grassland the only one in the process of compaction. Soil acidity is the main limiting factor for crop development, requiring the adoption of pH corrective practices with improvements in nutrient supply. The conversion of the forest to grassland maintained the structural characteristics of the soil, while the other uses increased improvements in physical quality and soil fertility.

Keywords: environmental covariates, physical and chemical attributes, soil management.

Análise multivariada na avaliação de atributos do solo em áreas sob diferentes usos na região de Humaitá, AM

RESUMO

O reconhecimento da influência das práticas de manejo nas condições físicas e químicas



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do solo é substancial para a agricultura sustentável. Por essa razão, o estudo foi desenvolvido com o objetivo de avaliar o comportamento de atributos do solo sob diferentes usos na região de Humaitá, AM, utilizando métodos estatísticos multivariados. O estudo foi desenvolvido em 8 propriedades rurais produtoras de banana, pastagem, milho, café, mandioca, hortaliças, sistema agroflorestal e fragmento florestal. Amostras de solos com estrutura preservada nas camadas de 0,0 - 0,10 e 0,10 - 0,20 m foram coletadas aleatoriamente em 5 pequenas trincheiras por área, totalizando 32 amostras nos sistemas de manejo, para determinar os atributos físicos e químicos. Os dados foram então submetidos à análise estatística univariada e multivariada. Análises exploratórias de dados (componentes principais e dendrogramas) e frequência de covariáveis ambientais foram eficientes em distinguir ambientes de produção, portanto a classificação multivariada baseada em atributos físicos e químicos do solo pode auxiliar no planejamento adequado do uso da terra. A análise dos componentes principais indica que a DS apresenta dependência direta com o RSP, sinalizando o uso do solo com pastagem o único no processo de compactação. A acidez do solo é o principal fator limitante para o desenvolvimento da cultura, exigindo a adoção de práticas corretivas de pH do solo com melhorias na oferta de nutrientes. A conversão da floresta para pastagem manteve a característica estrutural do solo, enquanto os demais usos incrementaram melhorias na qualidade física e fertilidade do solo.

Palavras-chave: atributos físicos e químicos, covariáveis ambientais, manejo do solo.

1. INTRODUCTION

The different systems of land use and management aim to create favorable conditions for crop development and yield (Costa *et al.*, 2013). As soil undergoes interventions in use, changes occur in its physical attributes, such as increased bulk density, decreased total porosity, pore diameter distribution, alteration in aggregation and organic matter content (Oliveira *et al.*, 2013). Thus, inadequate management leads to changes in soil properties, which, if maintained, leads to irreversible soil degradation, making agricultural practices unusable (Vasconcelos *et al.*, 2014; Gomes *et al.*, 2019).

The occupation and replacement of previously forested areas by agricultural areas without due technical criteria is one of the main problems caused by the anthropic action in the Amazon region. Problems that directly affect the preservation of natural resources, the soil attributes being the main physical and chemical indicators of these changes (Oliveira *et al.*, 2015). Studying the influence of different land uses in the southern Amazon, Gomes *et al.* (2017) reported that the use of grassland soil increased bulk density with reduction of total pore space and aggregate stability when compared to soil management with cocoa and coffee. In this same alignment, Aquino *et al.* (2014) found that conversion of forest areas to grassland increased soil resistance to penetration. In all of these studies, soil degradation was related to the decay of organic matter, due to its low specific density ranging from 0.9 to 1.3 g cm⁻³ (Reichert *et al.*, 2007), which gives it absorbing function or dissipating of compaction energies of the soil.

Recognition of soil changes imposed by changes in use is often not an easy task. Thus, soil variables, mainly structure-related, are used with indicators of physical and chemical quality. However, conventional and univariate statistical methods make it difficult to interpret the results when there are many variables involved in the process, hence the need to use multivariate analysis (Silva *et al.*, 2006; Oliveira *et al.*, 2018). Multivariate statistics allows the extraction from a set of original data of only the variables capable of explaining a significant part of the total variance of the data, through linear combinations (Silva *et al.*, 2016). Thus, fewer variables are required to be interpreted, summarized in only two dimensions (Freitas *et al.*, 2015).

In the Amazon region, some studies have focused efforts to evaluate the transformations occurring in the soil after the replacement of forest ecosystems for agricultural use (Aquino *et al.*, 2014; Oliveira *et al.*, 2015; Gomes *et al.*, 2018). From this point of view, knowledge of the

damages caused by different management systems is essential to improve the physical quality of the soil, since the conversion of forest to agricultural areas or grassland areas has been causing serious problems due to improper management (Soares *et al.*, 2016). Thus, aiming at the recognition of physical and chemical indicators of soil quality, this study was developed with the purpose of evaluating the behavior of soil attributes under different uses in the region of Humaitá, AM, using multivariate statistical methods.

2. MATERIAL AND METHODS

The sample collection was carried out in two communities in the rural area of Humaitá - AM, where soil samples were collected at five properties in the Realidade community, located at BR - 319, Km 100 of Humaitá - Manaus, and at three properties in Alto in BR - 230. The region presents relief similar to the type "tray", with very small differences and slightly bulging edges. These higher lands constitute the topographic dividers of water between the rivers of the region. The gap between these higher zones and the valleys of the igarapés is of the order of 15 to 29 meters; however, it occurs suddenly (Braun and Ramos, 1959).

Regarding the geology, the studied areas are located under an area formed from undifferentiated alluvial sediments, which are chronologically derived from the Holocene. The region has contact vegetation between field and forest, which is characterized by areas that include various formations, where the predominant vegetation is grassy, low woodland and alternates with small isolated trees and forest galleries along the rivers (Braun and Ramos, 1959).

All areas are located in the same climatic zone, according to the Köppen classification, belonging to group A (Tropical Rainy Weather) and climatic type Am (monsoon rainfall), presenting a short dry season (Brasil, 1978). The rainfall is limited between 2,250 and 2,750 mm, with the rainy season beginning in October and extending until June. The average annual temperatures alternate between 25 and 27°C and the relative humidity remains between 85 and 90% (Brasil, 1978). The soil of the study areas was classified as Cambissolo Haplico Alítico Plíntico - Brazilian Soil Classification (Embrapa, 2013; Campos *et al.*, 2011) equivalent to Inceptisol in the Soil Taxonomy (Soil Survey Staff, 1999).

Eight systems of land use were selected, typical of the Amazon region: a) Banana (*Musa spp.*): area with banana plantation with 4 years, without fertilization and correction, with spacing 3x3 m; b) Coffee (*Coffea canephora*): with 3 years of cultivation, with only soil correction and spacing 3x3,5 m; c) Native forest; d) Vegetables: area used for at least 8 years, without fertilization and correction; e) Cassava (*Manihot esculenta Crantz*) with spacing of 0.80 x 0.60 m, without liming and fertilization; f) Maize: approximately 120 days after planting in a conventional system; g) grassland: area cultivated with *Brachiaria (Brachiaria brizantha)* with approximately 10 years of use in extensive grazing; h) Agroforestry System: the area has been used for about 20 years, with coffee (*Coffea canephora*), cocoa (*Theobroma cacao*), palm trees (*Attalea speciosa*), andiroba (*Carapa guianensis*) among others for commercial and subsistence purposes.

In each system of use, an area of 80 × 80 m, with 16 sample blocks, was demarcated, the soils were collected in 5 small trenches per area, in the layers of 0.00-0.10 and 0.10-0.20 m, in soil-core with preserved structure, totaling 32 samples per management system.

The granulometric analysis of the soil was determined using the pipette method, with 1 mol L⁻¹ NaOH solution as chemical dispersant and mechanical stirring in a high rotation apparatus for 15 minutes (Embrapa, 2011). The total porosity (TP) was obtained by the difference between the mass of the saturated soil and the mass of the dry soil in an oven at 105°C for 24h (Embrapa, 2011). The microporosity of the soil was determined by the tension table method, according to Embrapa methodology (2011). By the difference between total porosity and microporosity, macroporosity was obtained. The bulk density (BD) was calculated

by the relation between the dry mass in the greenhouse at 105°C for 24 h of the soil sample of the volumetric cylinder and the volume of the same (Embrapa, 2011). Volumetric moisture was obtained by the difference between the wet soil mass and the dry soil mass in an oven at 105°C for 24 h (Embrapa, 2011).

For the determination of soil penetration resistance (SPR), the same samples were collected for bulk density (BD) and soil porosity, and the same were determined in the laboratory using an electronic penetrometer with a constant velocity of 0.1667 mm s⁻¹, equipped with a 200 N load cell, 4 mm diameter base cone and 30° semiangle, receiver and interface coupled to a microcomputer to record the readings using the equipment's own software. The determinations were performed in a sample with preserved structure, with water tension in the soil near the field capacity (Dalchiavon *et al.*, 2011). For each sample, 290 values were obtained, eliminating the 30 initial and 30 final values.

The determination of the stability of the soil aggregates was carried out by the wet sieving method. The separation and stability of the aggregates were determined according to Kemper and Chepil (1965), which was performed by placing the samples on a set of sieves with 2.0 mesh; 1.0; 0.5; 0.25; 0.125; and 0.063 mm and subjecting them to vertical oscillations for 15 minutes. The geometric mean diameter (GMD) and the weighted mean diameter (WMD) was adopted as stability index.

The pH was determined potentiometrically using a 1:2.5 ratio of soil in KCl. For the determination of exchangeable aluminum (Al³⁺), 1 mol L⁻¹ KCl was used as the extractor and 0.025 mol L⁻¹ NaOH was used as titrant in the presence of bromothymol blue as a colorimetric indicator (Embrapa, 2011). The potential acidity (H+Al) was determined volumetrically by titration of NaOH in calcium acetate at pH 7.0 as a reagent, in addition to phenolphthalein as an indicator (Embrapa, 2011). The chemical extractor used for the analysis of phosphorus (P) and potassium (K) is called Mehlich-1 (Embrapa, 2011).

The organic carbon (OC) was determined according to Walkley and Black methodology (1934) and modified by Yoemans and Bremner (1988), with organic matter being estimated based on organic carbon (Embrapa, 2011). The carbon stock (CS) was determined in all areas studied, and was calculated by the expression: $CS = (OC \times BD \times e) / 10$, where: CS = organic carbon stock of the soil (Mg ha⁻¹); OC = total organic carbon content (g kg⁻¹); BD = bulk density (Mg m⁻³); e = thickness of the layer considered (cm) (Costa *et al.*, 2009a).

A variance analysis was performed, and, when significant, by the f test, the data were analyzed by the Tukey test ($p < 0.05$). Multivariate statistical analysis was also performed, using hierarchical cluster analysis and principal component analysis (PCA) techniques. The analysis of hierarchical groupings was performed by calculating the Euclidean distance in the set of 13 original variables. This analysis allowed grouping the use of the soil (handling) by its similarities graphically represented in a structure called dendrogram of similarity. Then, the original sets of variables were subjected to factor analysis for a pre-selection of the variables with greater discriminatory power of the environments. The selected and non colinearized variables were submitted to PCA analysis, according to the criterion recommended by Hair *et al.* (2005). Thus, it was possible to construct a data dispersion graph (biplot) associative of the influence of the management on the alteration of the soil attributes, complementing the clustering analysis. All multivariate statistical analyses were processed in STATISTICA® software version 7.0 (Statsoft, 2004).

3. RESULTS AND DISCUSSION

In both evaluated layers the soil belonged to the same textural class, clay-loam (Table 1), dominating the silt fraction, which did not differ to 5% of significance in the 0.00-0.10m layer. Although there was no significant difference, the silt values increase in the following order: Forest (694 g kg⁻¹) > grassland (692 g kg⁻¹) > Banana (681 g kg⁻¹) > maize (674 g kg⁻¹) > coffee

(634 g kg⁻¹) > vegetable (633 g kg⁻¹) > AS > cassava (597 g kg⁻¹) at 0.0-0.10 m. Similarly, it occurred in the 0.10-0.20 m depth only for forest (674 g kg⁻¹), grassland (651 g kg⁻¹) and cassava (540 g kg⁻¹). These results are similar to other investigations carried out on soils under different uses in the Humaitá, AM region (Oliveira *et al.*, 2013; Mantovanelli *et al.*, 2015; Soares *et al.*, 2016).

It was verified that the bulk density (BD) was sensitive to the land-use practices, differing between cultivation and depth, which altered the others covariate attributes. The highest value of bulk density (BD= 1.50 Mg m⁻³) was found in grassland soil, which did not differ significantly between the layers. On the other hand, the cultivation of cassava in the layer 0.0 to 0.20 m caused a lower value of BD (1.04 Mg m⁻³), an increase of 16.13% to 0.10 – 0.20 m depth. The tilling and weeding of the soil prior to planting, as well as the practice of weeding and covering the ridges with the weeding material, justify the lower values of BD.

The management of soil did not significantly affect the soil properties microporosity (MiP) and the geometric mean diameter (GMD) in two layers with average diameter (WMD) and volumetric water content (Uws), differing only in layer 0.0 to 0.10 m. Several studies concerned with the mystification of the effect of management on the reorganization of the porous space of the soil conclude that the MiP does not change much in depth, and its increase reflects the deformations occurred in the MaP during the management (Giarola *et al.*, 2007; Vasconcelos *et al.*, 2014). Therefore, no significant difference was observed for MaP in the grassland, coffee, forest and vegetables areas, for both layers. However, it was the areas with lower values of MaP, showing in common similar values of BD, suggesting deformation of the macropores or clogging of these by the silt fraction, establishing soil compaction (Soares *et al.*, 2016).

The total porosity (TP) ranged from 0.44 to 0.58 cm³ cm⁻³ and did not differ for grassland system, the forest and AS layer from 0.0 to 0.10 m. However, for all types of soil use, the amplitude of TP values ranging from 0.44-0.58 cm³ cm⁻³, is below that recommended as ideal, which is 10%, indicating aeration conditions unsatisfactory for crop development (Baver *et al.*, 1972). However, it is worth noting that this criterion cannot be generalized, since there are plants tolerant to low levels of aeration.

Soil penetration resistance (SPR) presented high values of ≥ 2.00 kPa in forest and grassland soils in the 0.0-0.10 m layers, with decreases of 44.92% and 70%, respectively on the 0.10-0.20 m depth (Table 1). In fact, the highest SPR value found on the soil surface under grassland was due to animal trampling, which produces in the area in contact with hull a force greater than the soil can withstand (Gomes *et al.*, 2017; Debiasi and Franchini; 2012) (Table 1), which is consistent with the high values of BD (>1.50 Mg m⁻³), lower MaP (0.06 m³ m⁻³) and TP (0.44 cm³ cm⁻³). For Giarola *et al.* (2007), the reduction of TP in the grassland areas is due to the reduction of the MaP, since the MiP is little influenced by the soil management, as was verified in the present study.

The stability of aggregates expressed by WMD and GMD in the 0.10 – 0.20 m layer presented a significant difference among them, attributed to management specificity, growth habit, density and root thickness (Pedra *et al.*, 2012). The soil under forest presented higher WMD and GMD due to the greater input of vegetal material, which mixed with the soil matrix acts as a natural polymer aggregating or cementing the soil particles. A similar thing occurred with GMD in soils under grassland, motivated by the extensive development of the grass root system, considered the main particle aggregation agent in tropical soils, both by the release of exudates and by interlacing small clods and, consequently, forming larger structures (Salton and Tomazi *et al.*, 2014). This result corroborates those of Gomes *et al.* (2017) when assessing spatial variability of aggregates and organic carbon in different land uses in southern Amazonia. According to Campos *et al.* (2013), there is a highly significant correlation between the increase in organic matter content and the increase in aggregate stability; however, Alho *et al.* (2014) points out that a high WMD aggregate does not always have adequate pore-size distribution in the interior.

Table 1. Size and physical attributes of the soil of banana, grassland, maize, coffee, cassava, forest, Agroforestry system and vegetables in the layers 0.0-0.10 m and 0.10-0.20 m, in the region of Humaitá, AM.

Cultivation	Sand	Silt	Clay	SPR	MaP	MiP	Uws	TP	BD	GMD	WMD
	g kg ⁻¹			kPa		m ³ m ⁻³		cm ³ cm ⁻³	Mg m ⁻³	mm	
0.00–0.10 m											
Banana	97.89 b	681.97 a	138.12 c	1.20 bc	0.15 a	0.45 a	0.45 a	0.58 a	1.19 bcd	2.52 a	3.07 a
Grassland	109.07 b	692.42 a	139.33 c	3.00 a	0.06 c	0.37 a	0.37 a	0.44 c	1.50 a	2.68 a	3.15 a
Maize	139.16 b	674.94 a	166.45 bc	1.37 bc	0.16 a	0.41 a	0.41 a	0.56 ab	1.10 cd	2.65 a	3.16 a
Coffee	122.93 b	634.69 a	245.73 a	1.51 bc	0.10 bc	0.39 a	0.39 a	0.51 abc	1.21 bcd	2.42 a	2.98 a
Cassava	243.70 a	597.17 a	204.25 ab	0.85 c	0.13 ab	0.38 a	0.38 a	0.51 abc	1.04 d	2.50 a	3.11 a
Forest	111.32 b	694.42 a	138.58 c	3.05 a	0.06 c	0.37 a	0.36 a	0.45 c	1.36 ab	2.75 a	3.21 a
Agroforestry system	130.78 b	613.57 a	213.73ab	1.83 b	0.10 bc	0.38 a	0.38 a	0.48 c	1.32 abc	2.41 a	3.00 a
Vegetables	133.11 b	633.29 a	263.97 a	1.46 bc	0.08 bc	0.43 a	0.43 a	0.49 bc	1.31 abc	2.32 a	2.92 a
CV (%)	13.14	9.34	14.14	16.31	20.21	9.02	9.14	6.74	8.48	13.80	5.64
0.10–0.20 m											
Banana	72.29 c	616.71 ab	253.82 ab	1.59 b	0.09 bc	0.41 a	0.54 ab	0.52 ab	1.21 ab	2.57 a	3.07 a
Grassland	113.41 bc	651.71 ab	265.48 ab	2.11 a	0.06 c	0.39 a	0.56 a	0.45 c	1.56 a	2.42 a	3.03 ab
Maize	125.62 bc	645.54 ab	205.04 bc	1.50 b	0.09 bc	0.41 a	0.48 abc	0.49 bc	1.30 ab	1.83 a	2.62 b
Coffee	122.53 bc	619.15 ab	288.69 a	1.28 b	0.09 bc	0.42 a	0.42 c	0.50 abc	1.31 ab	2.54 a	3.08 ab
Cassava	190.58 a	540.06 b	280.98 ab	1.15 b	0.09 bc	0.41 a	0.37 c	0.50 abc	1.24 ab	2.57 a	3.08 ab
Forest	139.16 ab	674.94 a	166.45 ab	1.37 b	0.16 a	0.41 a	0.41 c	0.56 a	1.10 b	2.65 a	3.16 a
Agroforestry system	122.93 bc	634.69 ab	245.73 abc	1.51 b	0.10 b	0.39 a	0.39 c	0.51 abc	1.32 ab	2.42 a	2.98 a
Vegetables	149.72 ab	629.63 ab	251.01 ab	1.18 b	0.09 bc	0.43 a	0.43 bc	0.51 abc	1.34 ab	2.51 a	3.08 ab
CV (%)	19.90	7.90	13.99	15.08	15.06	5.40	10.73	5.81	9.44	17.65	7.05

SPR (Soil Penetration Resistance), MaP (Macro Porosity of soil), MiP (Micro Porosity of soil), TP (Total Porosity), Uws (volumetric water content), BD), GMD (Mean Geometric Diameter), WMD (Weighted Mean Diameter) CV (%): coefficient of variation. Means followed by the same letter do not differ from each other (Tukey $p \leq 0.05$).

The results for the chemical analyses are presented in Table 2. The pH values (4.29-4.95) classify the soil in all cultivation systems as acid to moderately acid (Embrapa, 2011), not differentiating between them. The low pH values favored the increase of the potential acidity (H+Al), which varied from 3 to 6 $\text{cmol}_c \text{dm}^{-3}$. In the different cultivation systems, especially in the maize and cassava areas, the potential acidity is considered strong and very strong, limiting soil fertility (Embrapa, 2011), due to the high Al^{3+} concentration available. According to Ernani (2008), pH values lower than 5.5 decrease organic matter decomposition, increasing the exchangeable Al^{3+} and the solubility of the iron and aluminum compounds. Therefore, in the pH values of the evaluated areas, the Al^{3+} readily available in the medium may lead to reduced growth and development of roots and reduced absorption of nutrients (Rampim *et al.*, 2013).

Table 2. Chemical soil attributes under different uses in the 0.0-0.10 m and 0.10-0.20 m layers in the Humaitá-Am region.

Cultivation System	pH	OC	CS	H+ Al	Al^{3+}	K	P
	H_2O	g kg^{-1}	Mg ha^{-1}		$\text{cmol}_c \text{dm}^{-3}$		mg dm^{-3}
0.0–0.10 m							
Banana	4.52 a	12.19 ab	64.92 a	16.17 a	5.27 a	9.88 a	2.37 ab
Grassland	4.82 a	7.61 c	19.32 c	10.60 a	2.95 b	5.60 a	1.93 ab
Maize	4.39 a	10.61 abc	39.25 bc	16.17 a	3.77 ab	10.46 a	3.21 a
Coffee	4.51 a	10.34 abc	53.50 ab	15.88 a	5.25 a	4.70 a	1.86 ab
Cassava	4.29 a	10.76 abc	47.15 ab	17.49 a	4.40 ab	5.17 a	2.42 ab
Forest	4.77 a	9.53 abc	19.06 b	10.64 a	2.94 b	7.03 a	1.63 ab
Agroforestry system	4.65 a	10.34 abc	40.08 abc	12.25 a	4.55 ab	5.67 a	1.21 b
Vegetables	4.64 a	13.03 a	65.26 a	15.01 a	5.07 a	4.72 a	1.63
CV (%)	5.70	17.90	24.99	21.14	17.72	42.29	33,08
0.10–0.20 m							
Banana	4.62 a	10.78 ab	25.84 a	15.13 ab	6.20 a	4.02 a	1.23 a
Grassland	4.51 a	7.17 b	20.98 a	9.65 c	4.10 ab	1.62 a	1.18 a
Maize	4.70 a	10.85 ab	28.26 a	11.50 bc	4.72 ab	3.87 a	1.27 a
Coffee	4.61 a	12.77 a	33.73 a	14.23 ab	5.70 ab	2.94 a	1.41 a
Cassava	4.42 a	11.58 a	28.76 a	12.62 abc	5.02 ab	4.32 a	1.35 a
Forest	4.39 a	6.61 b	23.26 a	16.17 a	3.77 b	4.17 a	1.27 a
Agroforestry system	4.95 a	8.67 b	24.90 a	15.88 a	5.25 ab	2.79 a	1.63 a
Vegetables	4.63 a	12.86 a	32.14 a	15.09 ab	4.82 ab	3.04 a	1.21 a
CV (%)	5.14	16.86	20.19	13.07	18.68	59.84	33.66

CV (%): coefficient of variation. Means followed by the same letter do not differ from each other (Tukey $p \leq 0.05$).

The carbon content (OC) in the soil in the different systems studied presented similar behavior, with the highest levels in the depth 0.0-0.10 m decreasing with depth increase (Table 2). The highest OC contents were found in the cultivated areas in the occurrence of the deposition of the cultural residues under the soil. The soil under cultivation of vegetables is highlighted, assuming the highest OC contents of 13.03 to 12.86 in the layer 0.0-0.10 and 0.10-0.20 m, respectively. This was due mainly to the short cycle of vegetables combined with the high C/N ratio, which conditions the easy decomposition (Silva *et al.*, 2016).

On the other hand, the practice of fires for grassland formation responds to the lower levels of OC in the soil under grassland, varying from 7.17 to 7.61 g kg^{-1} . In addition, Silva *et al.* (2004) argue that intensive grazing results in degradation of OC; added to this, we have the low input of OM by the grass. In turn, Campos *et al.* (2016) studying carbon stock and aggregates in a Cambisol under different managements in southern Amazonas, found OC content

(16.13 g kg⁻¹) higher than that found in the present study. The study by Campos *et al.* (2016) allows us to conclude that the increment of OC in grassland system depends on the grass species and the grazing system adopted.

The carbon stock (CS) followed the observed behavior for OC with higher content in the superficial layer of 0.0-0.10 m. Due to the characteristics of each crop, there was a significant difference in the supply of organic matter and, consequently, in the CS, with bananas, vegetables and coffee crops contributing the most to soil CS at 0.0-0.10 m depth. In the 0.10-0.20 m layer, there was a significant similarity between the cultivation systems, with the highest content being promoted in the soil with coffee (CS = 33.73 g kg⁻¹) and vegetables (CS = 32, 14 g kg⁻¹). Although in all cultivations the CS decreased with depth, the decay in the order of 63.05% g kg⁻¹ for banana, 50.75% g kg⁻¹ for coffee and vegetables with 39% g kg⁻¹ is related the contribution of the root system, an important contributor to the CS in depth. Behavior, which explains the increment in 7.9% and 18.05% in the soil with grassland and forest, respectively, at depths of 0.10 – 0.20 m.

The available phosphorus levels did not differ significantly between the cultivation systems, with similar behavior at all depths, varying from 1.21 to 3.21 mg kg⁻¹. A small decrease in depth, according to Silva *et al.* (2006), phosphorus remains stable in depth due to its low mobility and its compounds. Richter *et al.* (2011) observed an increase of the surface concentration (0.00-0.10 m) of phosphorus and other attributes of the soil. The decrease in OM content and the increase in iron and aluminum content reduce P availability in depth. Behavior was also noted for K levels that did not differ between cultivation systems, with higher values in the soil with bananas, maize and forest in the 0.0-0.10 m layer.

The dendrogram obtained by the cluster analysis allowed the formation of groups with similarity between the management systems and physical and chemical characteristics in the soil (Figure 1). The variation of the Euclidean distance in function of the similarity and non-similarity of the management allowed an exact division of the system of use of the soil in three groups (I, II and III) in the layer 0.00-0.10 and four to 0.10-0.20 m (IV, V, VI, and VII). Positioned at the end, the GI, consisting of forest and grassland, indicates that the characteristics imposed on the soil are very different from the other groups, mainly the GIII. The bifurcation that separates the GII and GIII groups evidences that the cultivation of cassava, vegetables, AS and coffee promote closer characteristics in the soil, and are far more similar to the use of maize and banana, GIII.

Considering the group formed in the layer 0.0-0.10 m (Figure 1A), there was a reorganization of the groups in the layer 0.10-0.20 m (Figure 1B). It is observed an isolated formation of the soil characteristics of GVI and GIII, indicating that there is no similarity of the forest and maize soil with the other groups, corroborating the results presented in Tables 1 and 2. Also consistent results are those of Freitas *et al.* (2015), studying the changes in the chemical and physical attributes of the soil submitted to sugarcane, forest and reforestation, with the use of dendrogram and other multivariate statistical techniques. The distinct behavior between the depths studied reinforces that the use of the soil changes its physical and chemical properties, due to the peculiarities of the handling and the capacity that each type of use entails.

The attributes of the soils evaluated by factor analysis (Table 3), allowed us to evaluate the attributes that presented higher factor loads by the varimax method. This procedure defines which attributes presented discriminatory power in common for the studied management, selecting attributes that can be considered as potential indicators of the original changes of the soil. The first two factors explained 78.00% and 57.69% of the total data variance in the two layers, revealing that only the sand attribute does not have a high factorial load. The SPR, MaP, MiP, TP, Uws, WMD, GMD, OC, CS, H+Al, Al³⁺ and pH were the most relevant attributes for the determination of Factor 1 that explained 52.14% and 35.39% of the total variance in the

two studied layers, respectively. The attributes clay, silt, K and P were explained in Factor 2 with 25.86% and 22.29% of the variance in the two studied layers, respectively.

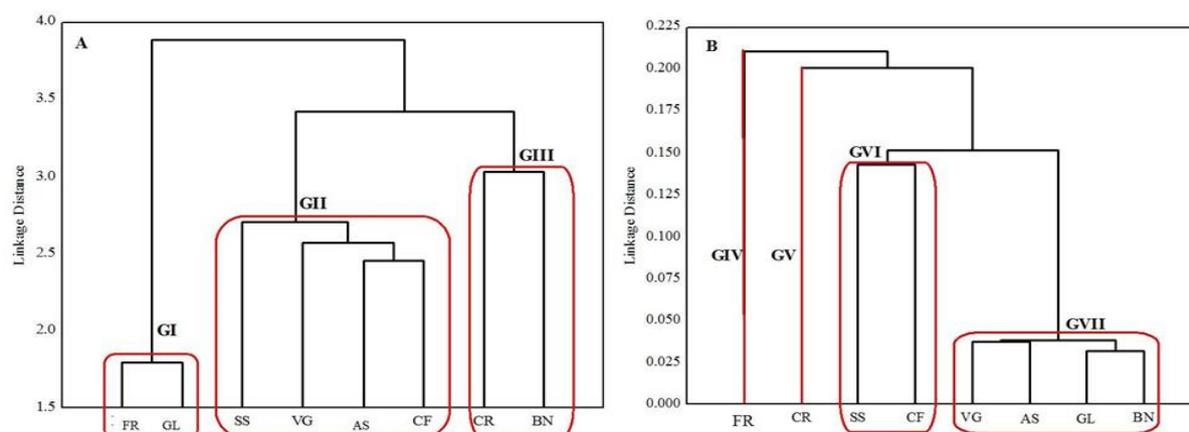


Figure 1. Dendrogram resulting from the hierarchical analysis of clusters showing the formation of groups (I, II, III, IV, V, VI, VII) according to the type of soil use (BN = bananas, GL = grassland, CR = maize, CF = coffee, SS = cassava, FR = forest, AS = agroforestry system, VG = vegetables) for layers A (0.0-0.10 m) and B (0.10-0.20 m) respectively.

Table 3. Factors extracted by principal components, highlighting attributes with loads higher than 0.7 (modulus) for soils under different management.

Attributes	CP 1	CP 2	CP 1	CP 2
	Layer 0.0 – 0.10 m		Layer 0.10 – 0.20 m	
Soil penetration resistance	0.973982	0.014616	-0.851957	-0.433365
Macroporosity	-0.785679	0.549132	0.778896	-0.601862
Microporosity	-0.727773	0.115549	0.589004	0.442441
Total porosity	-0.838293	0.474199	0.915874	-0.348526
Volumetric soil moisture	-0.759118	0.091025	-0.691887	-0.190896
Bulk density	0.811004	-0.334664	-0.904685	0.197828
Geometric Mean Diameter	0.634630	0.753223	0.414200	-0.033960
Weighted mean diameter	0.512307	0.801038	0.371930	-0.069967
Sand	-0.368536	-0.045991	0.078420	-0.018064
Silt	0.500849	0.595218	-0.152352	-0.719980
Clay	-0.468387	-0.794624	-0.333917	0.814386
pH on water	0.815923	-0.287279	-0.165962	0.233384
Organic carbon	-0.831751	-0.221428	0.251466	0.915309
Carbon stock	-0.737664	-0.476332	0.403844	0.802689
Potential Acidity	-0.942766	0.133433	0.824352	-0.091562
Aluminum	-0.827362	-0.416827	0.131536	0.707473
Potassium	-0.223108	0.866237	0.751332	-0.011715
Phosphor	-0.441862	0.806093	0.204458	0.185252
Eigenvalues	9.907264	4.913975	6.725936	4.236814
% of total variance	52.14349	25.86302	35.39966	22.29902
Cumulative eigenvalues	9.90726	14.82124	6.72594	10.96275
Cumulative %	52.14349	78.00652	35.39966	57.69868

The graphical representation and the correlation of the variables in the principal components (Figure 2AB) allowed to characterize the variables that more discriminated the formation of groups I, II, III, IV, V, VI, VII. With potential for explanation of 86.38% and 79.74% of the total data variance, CP1 revealed that grassland and forest environments (GII) were characterized by BD and SPR attributes, indicating a soil compaction process. However, this affirmation is only possible for the soil under grassland, since at both depths the grassland area (GVII) was related to the physical parameters BD and SPR indicators of soil compaction

(Aquino *et al.*, 2014; Vasconcelos *et al.*, 2014). It is possible that the content very close to the silt fraction in the 0.00 - 0.10 m layer has characterized grassland and forest soils as similar, because the small size of this particle obstructs the soil pores (Resende *et al.*, 2002), raising the values of BD and the SPR. In addition, it indicates that area under grassland is not in the process of intense compaction.

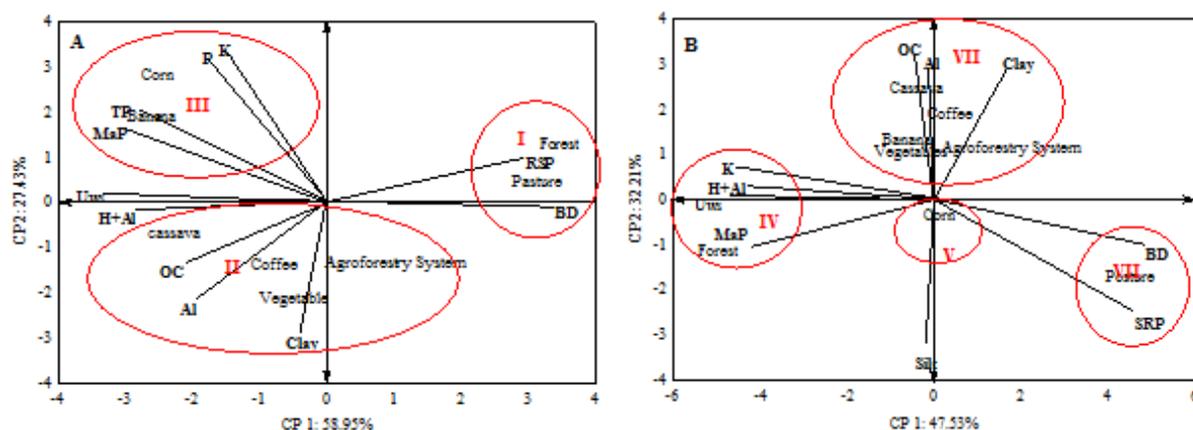


Figure 2. Dispersion (biplot plot) of the physical and chemical attributes in the different land uses, for layers a (0.0 - 0.10 m) and b (0.10 - 0.20 m). Indications I, II, III, IV, V, VI, VII are the groupings obtained in the cluster analysis.

The attributes H+Al, MaP, Uws and K defined the natural and conservative conditions of the forest area (GIV), consistent with the observations of Freitas *et al.* 2015 (Oliveira *et al.*, 2018), potential acidity and macroporosity strongly correlated with forest environments in relation to agricultural soils. As found here, Campos *et al.* (2012) report that the potential acidity in Amazonian forest soils results from the leaching process promoted by the intense water regime associated with the best drainage conditions in the region. No anthropic interference, without the use of agricultural implements and cultural treatments, does not degrade the stability of soil aggregates and allows soil moisture. Incorporation of OM complexed with K in the soil matrix under the activity of the microbiota provide chemical structural improvements and soil improved physics (Gomes *et al.*, 2018).

Among the evaluated soil attributes, the attributes K and Uws were more influenced by land use as observed in the biplot plot (Figure 2AB). The diversity of land use promotes more heterogeneous environments, with a reflection on the most sensitive physical-water attributes, soil moisture (Stefanoski *et al.*, 2013), which is inversely proportional to BD and SPR (Machado *et al.*, 2008). In addition to this, it can be stated that K variability was attributed to the diffusive flux of K influenced by soil moisture and soil compaction. For Costa *et al.* (2009b) and Ohland *et al.* (2014), the elevation of BD intensifies the aggregation force and reduces the macroporosity, thus hindering the mobility and absorption of K by the plants, due to the higher degree of hardness of the aggregates.

Only in the 0.0-0.10 m layer was the formation of a specific crop group such as maize and banana differentiated from the other crops by high levels of K and P and improvement in physical quality, verified by TP, contributing to the larger values of MaP. The formation of this group was also verified in the GIII cluster analysis (Figure 1A), probably as a consequence of the highest root volume in the first 0.1 m. The two CPs (0.0-0.10 and 0.10-0.20 m) revealed that the attributes clay, OC and Al were responsible for discriminating the GII and GVII groups, corresponding to the use of the soil with cassava, vegetables, coffee and agroforestry system.

The frequency histograms of the environmental covariates used and the descriptive statistics of the continuous covariates are shown in Figure 3. Most BD values are distributed in

the class between 1.10-1.40, with frequencies of 30%, 24% and 22% for areas 5, 7 and 1, respectively. Low BD values group areas 3 and 2 with a percentage of occurrence of 10% and 5% in the class 1.00-1.10 respectively. The other areas presented non significant values. For the SPR was (Figure 3B) larger frequency between classes from 0.0 to 2.0 with a frequency of 25%, 17%, 15% and 12% for the areas 2, 3, 4 and 6, respectively. Thus, it was possible to classify most studied fields, such as low - SPR points exist even in areas that are higher than the class of 2.50 considered critical for root development of the plants (Tormena and Roloff, 1996).

The frequency distribution of MaP (Figure 3C) presented higher frequency between the ranges 0.40-1.00, with values of 20%, 18%, 15% and 10%, for areas 2, 4, 1 and 8, respectively. The respective areas presented frequencies lower than 6%. As shown in Figure 3C, maize and AS areas were the ones with the lowest percentage of macroporosity.

According to Pereira *et al.* (2011), the volume of macropores is expressively decreased when the pressure exerted on the soil is greater than it can withstand, contributing to microporosity. These reasons have raised the percentage of MiP (Figure 3D), with higher frequency of classes 3.50-4.20 and 4.00-4.50, corresponding to 30%, 20%, 18% and 13% respectively for areas IV, V, VIII, II and I. The lower frequencies found in areas II and VI translate the good physical conditions for maize and forest areas, behavior also portrayed in previous analyses.

Two significant peaks in areas III and VI were observed for WMD (Figure 3E), with a percentage of occurrence of 16% and 28% for the intervals of classes 2.80 - 3.00 and 3.00 - 3.20. In general, most of the areas had a higher frequency in the range of 2.60 classes until the interval of class 3.20. Although the GMD presents frequency distribution similar to the WMD (Figure 3F), for most areas aggregate stability is grouped in class 2.50-3.00, with a minimum occurrence of 7%, except for areas IV and VIII that respond with frequencies above 10% and 15%. Given that GMD represents an estimate of the size of the highest occurrence aggregate class and the WMD the percentage of large aggregates, it can be stated that stable and larger aggregates are dominant in the evaluated areas, important in soil resistance to erosion (Aquino *et al.*, 2014; Vasconcelos *et al.*, 2014; Gomes *et al.*, 2019).

In Figure 3G, the pH values with the highest frequency are distributed in the class 4.5-4.6 with frequencies of 50%, the other areas presented frequencies equal to or less than 20%, from the class 4.30 to the class 4.90. This result corroborates those of Cunha *et al.* (2017), which state that most of the soils of the cultivated areas of the study region are acidic, with low cation exchange capacity, which translates into low natural fertility. In the VI environment, favorable conditions for OM accumulation and maintenance contributed to high potential acidity (Figure 3I), according to Silva *et al.* (2016) the abundance of organic acids in the forest soil releases H⁺ ions that will compose the potential acidity. This justifies the frequency percentage equal to or greater than 35% in forest areas and in their production environments VI, I, II and V.

Soil organic carbon presented values of frequency above 20% in the range of Class 10 (Figure 3H). The areas VI and II presented higher frequency, reaching values of 50%, 30% of frequency, respectively, due to the higher OM production and maintenance. In fact, the forest environment is an important CO₂ mitigating reservoir. In the case of soil under maize cultivation, the practice of leaving straw on the soil culminated in the increase of OC in area III. Summarizing, frequency histograms of environmental covariates based on soil attributes can assist in the identification and monitoring of natural areas being converted to agricultural activities, thus leading to proper management of agricultural crops and safety of chemical and physical quality from soil.

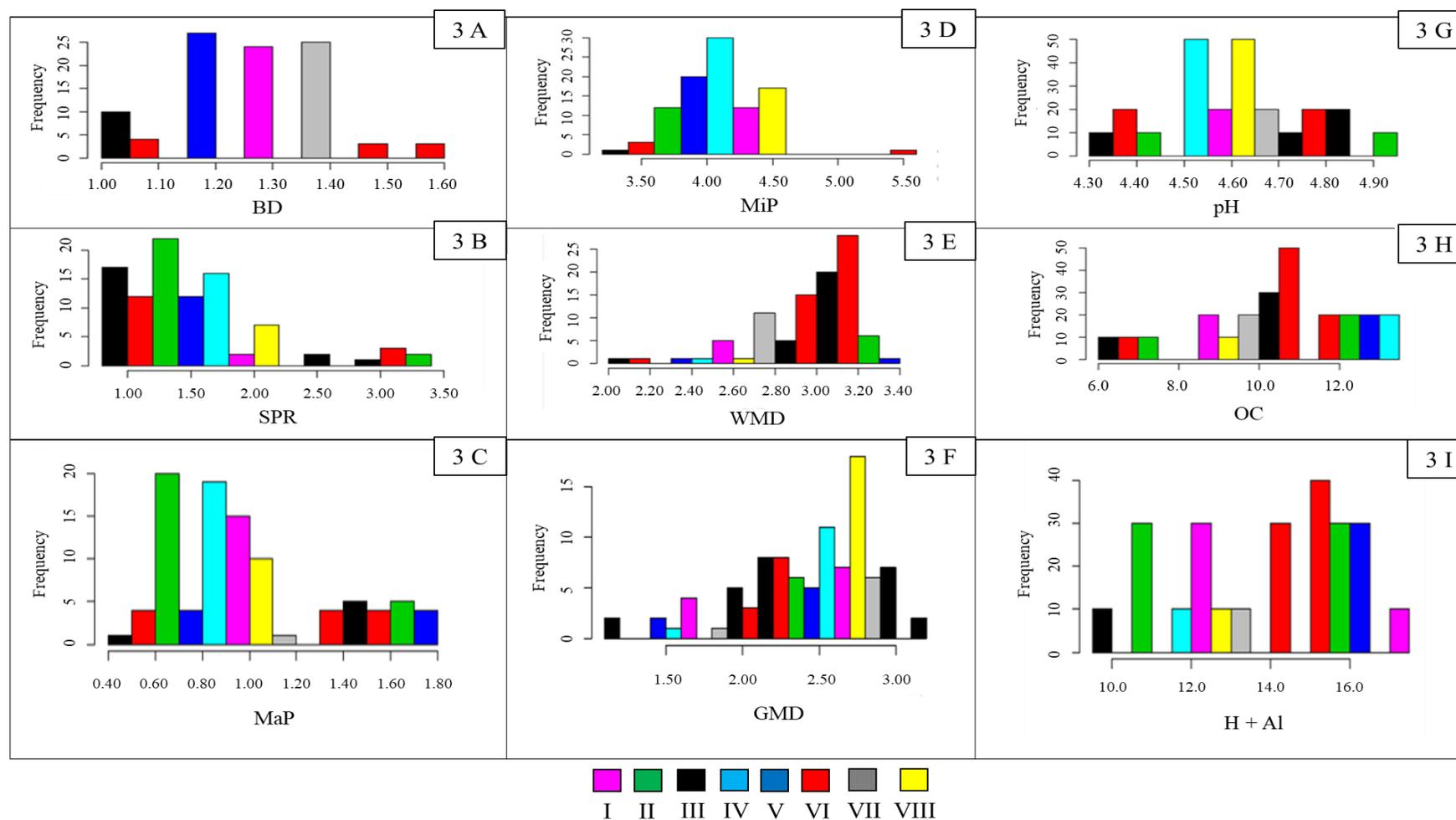


Figure 3. Distribution of the Bulk density Frequency 3 A; Soil penetration resistance 3 B; Macroporosity 3 C; Microporosity 3 D; Weighted average diameter 3 E; Geometric mean diameter 3 F; pH 3 G; Organic Carbon 3 H; Potential Acidity 3 I. I: Banana; II: Grassland; III: Maize; IV: Coffee; V: Cassava; VI: Forest; VII: AS; VIII: Vegetables.

4. CONCLUSIONS

The exploratory data analysis (principal components and dendrogram) and frequency of environmental covariates were efficient in distinguishing the production environments; thus, multivariate classification based on the physical and chemical attributes of the soil can aid in the proper planning of soil use.

The analysis of the principal components indicates greater variability for the attributes K and Uws, showing sensitive pedoindicators of land use.

Soil acidity is the main limiting factor for crop development, requiring the adoption of corrective pH practices with improvements in nutrient supply.

The conversion of the forest to grassland maintained the structural characteristics of the soil, while the other uses increased improvements in physical quality and soil fertility.

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