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Physical attributes of soil under amazon forest conversion for different crop systems in southern Amazonas, Brazil

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Abstract: The conversion of forested areas into cropping systems modifies the soil physical attributes and affects the environmental and economic sustainability of agricultural activity. Thus, this work aimed to evaluate the midifications caused in the physical attributes of the soil in the area of guarana, cupuacu and annatto compared with forest area in southern Amazonas. In the areas of forest and guarana meshes of 90 x 70 m and regular spacing between the sampling points of 10 x 10 m, in the area of annatto meshes of 90 x 56 m and spacing of 10 x 8 m, for cupuacu meshes of 54 x 42 m, with spacing between the sampling points of 6 x 6 m. The samples were collected in the depths of 0.00-0.05; 0.05-0.10; and 0.10-0.20 m, with 80 sampling points in each area, making 960 samples in the four areas. The cupuacu area most closely resembled the most diverse aspects of soil physical attributes with the forest area and this was noticeable through the averaging test along with the principal component analysis, thus indicating that this crop is the least harmful. to the studied soil, as well as the adopted systems of cultivation cause modifications mostly superficially, being these modifications little noticeable in layers superior to 10 centimeters.

Key words: Soil degradation; Amazon soils; soil attributes; multivariate analysis.

INTRODUCTION

In recent years, the conversion of natural environments to agricultural systems, especially monoculture systems, has led to changes in the soil (Silva et al. 2007, Freitas et al. 2015). Among the factors that contribute to soil degradation, the use and management are more aggravating because they alter the attributes of the soil attributes, contributing to a possible imbalance of the systems and consequently the environment changes in bioduversity (Costa et al. 2015).

Physical indicators such as soil density, porosity and aggregate stability have been frequently used to assess soil quality. These indicators are related to the organization of soil particles and pore space, reflecting thelimitations of root growth, seedling emergence, infiltration and percolation of soil water (Cunha Neto et al. 2018).

Recent studies also highlight that soil physical attributes are good indicators of quality and allow monitoring of areas that have suffered some kind of interference (Aquino et al. 2014; Freitas et al. 2018). Thus, with negative changes in the physical attributes of the soil, entails a series of changes among them related to the attributes involved in soil porosity and density, and consequently influencing the dynamics of carbon and organic matter in the soil, thus contributing to a possible degradation (Souza et al. 2014).

For the interpretation of variations in soil attributes it is necessary to use statistical methods. The univariate methods have limitations, since the behavior of attributes is interpreted in isolation, without taking into consideration interaction with the other attributes present, and thus, an option to facilitate the work with data that presents / displays great number of variables is by the use of multivariate analysis (Silva et al. 2010). Through the multivariate analysis technique it is possible to explain the maximum intercorrelation between the variables and to find out which of them contribute more to the characterization and / or alteration of the soil, besides being an efficient tool, if one intends to carry out simultaneous analysis of many variables (Oliveira et al. 2015, Aquino et al. 2016).

Therefore, the objective of this work was to evaluate the physical attributes of the soil in areas under guarana, cupuacu and annatto crops, compared to the forest area.

MATERIAL AND METHODS

LOCATION AND CHARACTERIZATION OF THE STUDY AREA

The study was conducted in two rural properties that are part of the São Francisco settlement located in the municipality of Canutama, Amazonas, Brazil under the geographic reference coordinates (8º 13' 23'' S; 64º 00' 50'' W) and (8º 13' 25'' S; 64º 00' 23'' W), in both properties. Four areas were selected, three of them with the first uses: Annatto (*Bixa orellana* L.); Cupuacu (*Theobroma grandiflorum* (Willd. ex. Spreng) Schum) and guarana *(Paullinia cupana* (Mart.) Ducke) and a forest area (Figure 1).

The soil of the study area was classified as Red-Yellow Argisol located in the Amazonian Plain between the Purus and Madeira rivers, it is associated with old alluvial sediments, (upper terraces of the prestocene) of the Quaternary period, characterized by the presence of large tabular reliefs, defined by very weak depths, very smooth slopes and natural drainage is deficient (EMBRAPA, 2018). Regarding the climatic characterization, the climate of the region is rainy tropical, presenting a short dry period. The average rainfall varies between 2250 and 2750 mm per year, with a rainy period between October and June. The mean annual temperatures vary between 25 and 27º C and the relative air humidity between 85 and 90% (Brasil, 1978).

As for the history of use and management of the selected areas for the study, it was possible to gather important and relevant information, that can help in the discussion of it. The areas cultivated with guarana and cupuacu have 7 years of effective cultivation, and the area of annatto only 3 years. It is important to emphasize that the respective areas are derived from logging and burning of the forest, and manual cleaning in the first year of cultivation. There was never any type of fertilization and liming in the cultivated areas, however, there was only weed control with the use of a motorized ridge, besides spraying with glyphosate herbicide to control thatch (*Imperata brasiliensis*), was carried out. The areas of guarana and annatto present an average slope around 3%. The cupuacu area is located in a flatter area, and it is possible to observe the effective accumulation of biomass of the crop in large quantities. The forest area selected for comparison purposes is characterized as tropical forest dense ombrophilous, whose vegetation is perennial, consisting of densified and multi-layered trees between 20 and 50 meters high.

FIELD METHODOLOGY

Meshes were established according to the size of the crop. In the areas of guarana and forest, 90 x 70 m meshes were established with regular spacing between the sampling points of 10 x 10 m, however, in the area of annatto the established mesh was 90 x 56 m with spacing between the sample points of 10 x 8 m, for the cupuacu area the mesh was 54 x 42 m, with regular spacing between the sample points of 6 x 6 m. The samples were collected at the crossing points of the meshes, specifically in the crown projection at depths 0.00-0.05; 0.05-0.10; and 0.10-0.20 m, with 80 sample points in each area, totaling 240 samples per area. The points were georeferenced with a Garmin GPS equipment model Etrex (*Datum South American* '69).

At each sampling point, volumetric rings of 4.0 cm in height and 5.1 cm of internal diameter were collected, and samples with a preserved structure were collected in the three layers evaluated for determination of the physical attributes, texture and mechanics of the soil, a total of 960 samples in the four areas evaluated. The samples were dried in the shade and slightly deformed, passed through a 9.51 mm mesh screen, separating the material retained in the 4,76 mm sieve for analysis on the stability of aggregates. Samples retained in the 2.00 mm sieve were used for soil texture analysis.

LABORATORY DETERMINATIONS AND ANALYSIS

The stability of the soil aggregates was determined by the wet sieving method. The separation and stability of the aggregates was determined according to Kemper & Chepil (1965), with modifications in the following diameter classes: 4.76-2.0 mm; 2.0-1.0 mm; 1.0-0.50 mm; 0.50-0.25 mm; 0.25-0.125; 0.125-0.063 mm.

The aggregates from the 4.76 mm sieve were placed in contact with water on the 2.0 mm sieve and submitted to vertical stirring in Yoder apparatus (SOLOTEST model) for 15 min and 32 oscillations per minute, since for each type of series we use a pendulum set, more than 2 mm with the following diameters: 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, 0.063 mm. The material retained in each class of the sieves was placed in an oven at 105 ºC, then measured the respective masses in a digital scale. The results were expressed as a percentage of the aggregates retained in each of the sieving classes for >2 mm, 2-1 mm and <1 mm. It was calculated: weighted average diameter (WAD) and aggregate stability index (ASI) of the class <0.25 mm, both using the formula proposed by Castro Filho et al. (1998), the geometric average diameter (GAD) was calculated according to Schaller & Stockinger (1953), cited by Alvarenga et al. (1986), according to the following equations:

$$\text{WAD} = \frac{\sum_{i=1}^{N} n_i D_i}{\sum n_i} \quad (1)$$

$$\text{GAD} = 10^{\frac{\sum_{i=1}^{N} n_i \log D_i}{\sum n_i}} \quad (2)$$

Where:

ni is the percentage of aggregates retained in a given sieve, *Di* is the average diameter of a given sieve and *N* is the number of sieve classes.

$$\text{IEA} = \left(\frac{\text{MS - wp0,25 - areia}}{\text{MS - areia}}\right) 100 \quad (3)$$

Where:

MS - dry mass of sample, g,e; wp0.25 - aggregate mass of class <0.25 mm, g.

For the determinations of soil density (Sd), macroporosity (MaP) and microporosity (MiP), total pore volume (TPV) and gravimetric humidity (Ug), the samples collected in volumetric rings were saturated by gradually raising, up to two-thirds of the ring height of a water film on a plastic tray. After saturation, the samples were weighed and taken to the tension table to determine the MiP of the soil, the samples were submitted to a tension of -0.006 MPa. After reaching the equilibrium at a matrix potential of -0.006 MPa, the samples were again weighed and then the measurements of soil resistance to penetration (SRP) were performed, using an electronic bench penetrator (MA- 933, Marconi, SP, BR). Afterwards, the samples were taken to the oven at 105 ºC for the determination of Ug, Sd and TPV by the volumetric ring method, and the MaP will be determined by the difference between TPV and MiP (EMBRAPA, 2017). The texture analysis was performed by the method of the pipette using 0.1 N NaOH as chemical mechanical stirring and dispersing apparatus at high speed for 15 minutes, following the methodology proposed by EMBRAPA (2017). The clay fraction was separated by sedimentation, the sand by sieving and the silt was calculated by the difference. Pearson's correlation was used to evaluate the strength and direction of map correlation of the distribution pattern of these variables.

STATISTICAL ANALYSIS

After performing the analyzes in the laboratory, the data were first submitted to descriptive statistical analysis, which determined the values of mean, median, asymmetry and kurtosis coefficients, coefficient of variation and normality test, which were analyzed using the Software. Statistics 7.

Univariate analysis of variance (ANOVA) was used to compare attribute means individually using the 5% Tukey test. Then, the multivariate analysis of variance (MANOVA) was used, through factor analysis and clustering, in order to find statistical significance of the sets of soil attributes that most discriminate the environments, in order to obtain attributes that have greater influence on the response. land use.

The adequacy of the factor analysis was made by the Kaiser-Meyer-Olkin (KMO) measure, which evaluates the simple and partial correlations of the variables, and by the Barlett sphericity test, which aims to reject the equality between the correlation matrix and the correlation. identity.

The extraction of the factors was done by the main components, incorporating the variables that presented commonalities equal or superior to five (5). The choice of the number of factors to be used will be made by the Kaiser criterion (factors with eigenvalues greater than 1). In order to simplify the factor analysis, the orthogonal (Varimax) rotation of the factors was performed and represented in a factorial plane of the two components. All multivariate statistical analyzes were processed using STATISTICA version 8 software.

RESULTS AND DISCUSSION

When analyzing the results of the analysis of variance of the physical attributes at the depths (Tables 1, 2 and 3), using the Tukey's test ($p < 0.05$), it was found that the highest values of the attribute density (Sd) from 0.00 to 0.05 m depth, followed the sequence of guarana > annatto > cupuacu > forest, and the respective areas presented significant differences between them (Table 1). Higher values of Sd found in the guarana area, possibly is associated with the time that the crop is under intense agricultural exploitation (7 years), besides the use of fire to clean the area, since the main alterations that can occur with the firing are evidenced by the decrease in the volume of macropores, weighted average diameter of the stable aggregates and by the increase of the soil density, mainly in the superficial depth of the only (Redin et al., 2011).

According to Viana et al. (2011), the increase of soil density in cultivated area can also be explained by the reduction in organic matter content in the soil surface compared to the soil under native forest. In the depth 0.05-0.10 m, it was verified that the areas cultivated with guarana and cupuacu did not show any significant differences between them, but they were statistically different when compared to the area cultivated with annatto and forest, the forest with the lowest value of Sd (0.96 g cm^{-3}) (Table 1), this phenomenon is due to the fact that both areas are close and because they are rustic cultivars of the Amazon, that is, originating from this biome, they have common cultural treatments, which contributes to the differentiation of these environments.

The depth of 0.10-0.20 m, it was observed an increase in density value of the area under cultivation with cupuacu (1,16 g cm^{-3}), this area showed significant difference when compared to guarana, annatto and forest areas, this difference was expected, since areas that do not undergo soil rotation tend to occur high deposition of organic material in the soil surface, provided by the accumulation of vegetal residues of the crop itself (Hernani and Salton 2009, Guareschi et al. 2012, Torres et al. 2015).

When analyzing the results of the MaP, MiP and TPV attributes in depth 0,00-0,05 m, it was possible to observe that for the MaP attribute, the areas of annatto, cupuacu and forest did not present significant difference, both only differed significantly from the area cultivated with guarana, so that it presented lower value of MaP on the surface. This result can be explained by the higher soil density found in the guarana area, since it causes a reduction in macroporosity, according to Chioderoli et al. (2012) and Cardoso et al. (2013). The only exception occurred for the area under guarana at depth 0,00-0,05 and 0,05-0,10 m, where values below the reference were observed.

When analyzing the same attributes MAP, MIP and TPV, but this time the depths 0.05-0.10 and 0.10-0.20 m, it was observed that the respective attributes presented significant differences, and that the highest values of MaP and Pt were observed in the forest area for both depths. It is worth noting that MaP and TPV are inversely proportional to density (Chioderoli et al. 2012) and that, therefore, higher TPV values in proximity to the soil surface are generally found in areas under native forest (Luciano et al. 2010, Martinkoski et al. 2017).

It is possible to attribute the highest values of SRP found for the areas of guarana and annatto due to the low effective action of initial preparation of the soil. Adopting the classification of Couto et al. (2016), which classifies soil resistance values as penetration, it can be affirmed that the studied areas at all depths have SRP less than 2 MPa, a fact that characterizes soils without restriction to root growth. In general, it is feasible to give greater attention to the areas of guarana and annatto in order to both have presented higher values of SRP compared to the areas of forest and cupuacu, around 1.01 MPa.

When the attributes related to the soil structure GAD, WAD and IEA were analyzed in the depth of 0.00-0.05 m, it was observed that the highest values of the respective attributes were found in areas under forest, which shows a high degree of aggregation of the soil particles. The results corroborate with the work done by Luciano et al. (2010), where they observed better aggregation of the soil in natural forest, suggesting that this result may have been influenced by the greater biological activity, that is, these microorganisms will act on the decomposition of organic material (plant or animal) from the forest and this favors organic matter being closely related to soil aggregation. The lower values of GAD, WAD and IEA were found in the cupuacu area (Table 1), indicating that the continuous use of the area for a long period (7 years), without the adoption of any conservationist practices, led to the disintegration of soil particles, acceleration in the decomposition of organic carbon and the lower indexes of stability of aggregates in relation to the other areas studied.

When the results of the granulometric fractions were analyzed, a predominance of the silt fraction was observed in all areas, as well as for all studied depths, with values varying from 483.5 to 530.44 g kg^{-1}. Similar results were obtained by BRITO et al., (2018) and BRITO FILHO et al., (2018), studying the spatial variability of soil physical attributes in areas under coffee, cocoa and pasture uses in the southern region of Amazonas. After a general analysis of the results, it was possible to characterize the sand, silt and clay contents as medium texture for all depths evaluated.

Table 4 presents the Pearson correlation values at 0.05 and 0.01 significance levels for the physical soil attributes of all the studied areas. It was possible to observe that the Sd attribute presented a positive correlation with MiP (r = 0.16), Sand (r = 0.48) and SRP (r = 0.59). In contrast, the results indicated that the Sd is affected by the attributes MaP (r = -0.56), TPV (r = -0.22), Ug (r = -0.48), IEA (r = -0.13) and Silt (r = -0.51), both presenting negative correlation. These correlations evidenced that as the Sd increased, simultaneously the MiP and SRP increased, this fact indicates that the process of forest conversion in cultivated areas is promoting modifications in the soil structure, mainly in the increase of the compaction index, something that can prove such indicative is the occurrence of positive correlation of the Ds with the sand, since alone sandy soil are more susceptible to compaction (DONAGEMMA et al., 2016).

Regarding KMO Values (Kaiser-Meyer-Olkin), this is a measure that assesses the adequacy of factor analysis (TASSITANO et al., 2015), KMO index values and their classification varies from author to author, where acceptable values are between 0.5 to 1.0, so below 0.5 indicate that factor analysis is unacceptable. According (Reis, 2001) the rating goes from 1 to 0.5, where 1 is very good and below 5 is unacceptable. Considering that the values obtained through the analysis were KMO 0.85, 0.82 and 0.80, for the depths of 0.00-0.05, 0.05-0.10 and 0.10-0.20, respectively, then all the depths obtained the KMO classification as good.

Considering variance as a measure of dispersion, where this will indicate how far the values are from the expected values (YAMAMOTO et al., 2017), as well as that the variables with the highest variance are those that individually will have greater contribution to the total variance (PC1 + PC2) (FREITAS et al, 2015), the need to use two main components was observed considering the eigenvalues and total variance of 61.84% (table 5), corresponding to 35, 03 and 26, for PC1 and PC2, respectively. Evaluating the attributes individually, the largest contribution of the variance (0.93) of GAD and WAD to the total variance was noticeable, meaning a greater distance from the value of these attributes to the expected values.

In the second depth, the largest variance explained was in PC1, but the variance of the attributes that most contributed to the total variance was located in PC2, corresponding to the MiP and GH variables, these values corroborate the results found by Oliveira et al (2015). working with soil attributes in southern Amazonas. At a depth of 0.10-0.20 m, two components were needed, which explains 68.48% of the total variance. It was noticeable that the significant variances were mostly in PC1, but the attribute that had an individual shape. highest contribution, had its largest variance in PC2, being the GH.

The graphical representations of the components (figure 2: A, B and C) allow us to characterize the variables that most differentiated and discriminated in the formation and differentiation of the environment, that is, the variables that were most impacted and their behavior with the replacement of management. by cultivation areas (FREITAS et al., 2015). For a geometric interpretation, the weights assigned to each variable correspond to the projections to each of the coordinate axes represented by the main components (MANLY, 2008).

At the depth of 0.00-0.05 (Figure 2A), it is noted that the forest and cupuassu area scores were similarly concentrated in the third and fourth quadrants, differing from the other two areas of annatto and guarana, which thickened in the first and second quadrants. Thus, in the forest and cupuassu areas were found above average values of MaP and Silte positively correlated with PC2, as well as they were below average for the areas of annatto and guarana, on the other hand sand, RSP, SD and MiP. were above average for the areas of guarana and annatto and also positive relation to PC2, these results corroborate with Cunha (2016) in a study of soils in the Amazonian environment.

This phenomenon is due to the fact that in addition to the impact caused by the replacement of native forest by the cultivated area, the management used for each crop must also be questioned, and this would be the key point where it is observed that the crop of the annatto and guarana are of shrub size and their management are similar, where after their harvest in a certain part of the year is pruned, besides being very close areas and all these factors contribute to the similarity of these two environments in distinction with the areas of Cupuacu and forest. This way with the more intensive management in the areas of annatto and guarana, this favors the densification of the soil due to the traffic of people, which reduces the amount of macropores and increases the amount of micropores and consequently increases the resistance of the soil to penetration. This explains the fact that the values of these variables are above average for both areas (ALVES et al., 2015).

Regarding the aggregation values, it was observed that IEA, GAD, WAD and> 2.00 had their values above the average for the forest and guarana areas, positively related to PC1, in contrast these two areas had values below the average for the aggregate class <1.00 mm, which obtained above average values for the cupuassu area, is due to the fact that particles larger than <1.00 mm and> 2.00 mm are antagonistic, and proportional . It was also observed that these aggregation values did not cause differentiation of areas, unlike porous spaces, and these are the attributes that suffer the most from the impacts caused by management.

The values shown graphically in Figure 2B, referring to the second depth, refer to the soil attributes, where these were more explained and correlated with the main component 1 (46%), where for the forest and guarana areas that their scores concentrated in the second quadrant, the MiP, GH and TPV variables were above average and positively related to PC1, and below average for the cupuassu area. Another fact observed was the location of the annatto area scores in the first quadrant, with values above the average for the GAD, WAD and IEA variables, but with values below the average of aggregate classes <1.00 mm and 2.00 -1.00 mm, the cupuassu area had its scores in the third and fourth quadrants, where it obtained values above the average with the size aggregate class of 2.00-1.00 mm, and below the average for the porous variables. . The map showed the great distinction between the cupuassu area and the other areas, which can be attributed to the older management in the cupuassu area, where the impact of management is still superficial due to the short time of use (SOUZA, 2016).

In the third depth (figure 2C) the annatto scores were concentrated in the second and third quadrants, with values above average for aggregation variables, and positive correlation with PC1, although similar scores can still distinguish the cupuassu area from other areas, but now with above average GH, TPV and MiP values. This indicates that Even at greater depths, soil structure is a crucial factor in the differentiation of environments, where even the largest is in relation to porous spaces, even when dealing with low intensity management environments (BAUTLER et al., 2018).

Conclusions

The conversion of native forest areas into cultivated areas, even with native species, causes changes in the physical attributes of the soil.

The lower slope in the forest and cupuacu areas was one of the factors that contributed to the similarities of attributes between the areas, unlike the annatto and guanará (nearby areas).

The management adopted in the areas caused significant changes in the soil only to a depth of 10 cm, not being as expressive from 10 cm.

The attributes that suffered the most changes in forest conversion in cultivated environments were: Sd, MaP, MiP, TPV, SRP and IEA.

The area under forest has been confirmed as the ideal condition for the maintenance of the physical quality of the soil under the conditions studied, while, it presented a greater expression of the physical attributes that are compatible with the sustainability of the system.

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Figure 1. Location and digital elevation model of the areas with guarana, cupuacu, annatto and forest in the municipality of Canutama, southern Amazonas – AM.

source: google maps.

Figure 2. Analysis of principal components of soil physical attributes in the three studied depths corresponding to areas under forest conversion in cultivated areas in the South of Amazonas. A: depth 0.00-0.05 m; B: depth 0.05-0.10 m and C: 0.10-0.20 m.

Table 1. Mean test and descriptive statistics of the physical attributes in the depth of 0.00-0.05 m for areas with different uses in the south of Amazonas.

Descriptive statistics	Sd	MaP	MiP	TPV	GAD	WAD	IEA	HG	SRP	Sand	Silt	Clay
	g cm^{-3}	------ m^3 m^{-3}------		----- mm -----		----- % -----		MPa		----- g kg^{-1} -----		
Guarana												
Average	1,10 *a*	9,00 *b*	36.67 *a*	46,00 *a*	2,79 *a*	3,19 *a*	93,92 *b*	34,00*bc*	0,89 *a*	390,03 *a*	392,99 *c*	216,98 *a*
Medium	1,11	9,00	37.018	46,00	2,81	3,19	94,54	34,00	0,90	389,92	391,99	216,00
SD	0,10	3,00	4.473	4,00	0,24	0,07	3,09	6,00	0,29	47,98	40,63	32,04
CV (%)	9,51	31,95	12.2	8,87	8,74	2,12	3,29	17,8	32,20	12,30	10,36	14,87
Asymmetry	-0,19	0,89	0.05	0,44	-1,30	-0,56	-1,64	0,32	-0,26	0,08	0,22	-0,45
Curtose	-0,22	1,14	-0.19	0,36	2,32	0,09	3,90	0,57	-0,79	-0,53	-0,30	-0,05
K-S	0,05*	0,10*	0,07*	0,063*	0,11*	0,11*	0,12*	0,05*	0,18*	0,06*	0,09*	0,13*
Annatto												
Average	0,99 *b*	15,36 *a*	34,85 *b*	47,90 *a*	2,76 *a*	3,18 *a*	92,87 *b*	35,26 *b*	0,62 *b*	378,10 *a*	445,29 *b*	176,61 *b*
Medium	1,00	14,03	34,698	47,50	2,80	3,20	93,71	34,85	0,59	375,10	442,29	175,61
SD	0,14	5,39	3,398	4,43	0,27	0,09	4,17	5,64	0,28	51,94	56,11	40,27
CV (%)	14,44	35,07	9,75	9,24	9,89	2,88	4,49	16,00	45,97	13,85	12,69	22,93
Asymmetry	0,03	0,85	0,19	0,07	-0,84	-1,52	-1,09	0,02	1,45	0,57	0,25	-0,11
Curtose	0,81	0,17	1,03	0,22	0,01	2,84	0,60	1,48	4,50	-0,43	0,04	-1,04
K-S	0,06*	0,12*	0,09*	0,06*	0,16*	0,17*	0,15*	0,09*	0,05*	0,10*	0,10*	0,12*
Cupuacu												
Average	0,92 *c*	15,43 *a*	27,31 *c*	40,39 *b*	2,53 *b*	3,08 *a*	91,12 *c*	30,52 *c*	0,40 *c*	263,77 *b*	519,49 *a*	216,74 *a*
Medium	0,92	4,09	27,165	4,43	2,53	3,08	91,58	6,20	0,35	265,50	519,64	209,20
SD	0,10	26,50	4,253	10,97	0,25	0,10	3,96	20,33	0,18	34,15	43,03	33,42
CV (%)	10,84	15,96	15,57	40,05	9,90	3,41	4,34	29,90	45,76	13,00	8,28	15,52
Asymmetry	-0,25	0,08	-0,07	0,32	-0,16	-0,31	-0,94	0,93	0,61	0,24	0,13	-0,01
Curtose	-0,11	-0,33	-0,54	-0,16	-0,88	-0,80	0,55	1,49	-0,44	-0,83	-0,38	-0,33
K-S	0,06*	0,06*	0,05*	0,08*	0,08*	0,10*	0,09*	0,13*	0,08*	0,09*	0,04*	0,14*
Forest												
Average	0,87 *d*	15,34 *a*	34,38 *b*	47,65 *a*	2,82 *a*	3,20 *a*	95,64 *a*	40,93 *a*	0,43 *c*	252,19 *b*	530,44 *a*	217,37 *a*

Medium	0,87	15,29	34,664	47,87	2,85	3,20	95,80	40,32	0,39	252,00	529,01	215,37
SD	0,13	5,48	4,694	6,40	0,23	0,07	2,05	11,68	0,20	26,12	37,53	31,96
CV (%)	15,14	35,69	13,65	13,43	8,26	2,17	2,14	28,54	47,37	10,48	7,09	14,84
Asymmetry	0,14	0,25	-0,19	-0,60	-0,58	-0,28	-0,74	0,45	0,76	0,03	-0,02	-0,59
Curtose	0,16	-0,55	-0,69	0,14	0,05	-0,71	0,52	1,45	-0,25	0,13	0,83	0,98
K-S	0,07*	0,07*	0,08*	0,08*	0,07*	0,07*	0,08*	0,08*	0,43*	0,07*	0,07*	0,15*

Note: Means followed by the same lowercase letter in the column do not differ by Tukey test ($p < 0.05$).
SD: standard deviation; CV: coefficient of variation (%); K-S: Kolmogorov-Smirnov normality test. * Significant at 5% probability; Ds: soil density; MaP: macroporosity; MiP: microporosity; TPV: total porosity; DMG: geometric mean diameter; WAD: weighted mean diameter; IEA: Aggregate Stability Index; HG: gravimetric humidity: RPS: soil resistance to penetration;

Table 2. Mean test and descriptive statistics of the physical attributes in the depth of 0.05-010 m for areas with different uses in the south of Amazonas.

Descriptive statistics	Sd	MaP	MiP	TPV	GAD	WAD	IEA	HG	SRP	Sand	Silt	Clay
	g cm^{-3}	------ m^3 m^{-3}------		----- mm -----		----- % -----		MPa		----- g kg^{-1} -----		
Guarana												
Average	1,12 *a*	9,77 *d*	35,89 *a*	45,58 *b*	2,44 *c*	2,96 *bc*	91,12 *b*	32,28 *b*	1,01 *a*	363,61 *b*	410,86 *b*	225,53 *c*
Medium	1,11	3,36	36,000	5,15	2,51	3,01	92,49	5,27	0,99	357,30	407,16	228,65
SD	0,07	34,34	3,465	11,29	0,43	0,24	5,07	16,33	0,40	41,52	39,93	52,07
CV (%)	5,95	9,39	9,66	45,39	17,42	8,00	5,56	32,51	39,72	11,42	9,68	23,09
Asymmetry	0,60	0,76	-0,39	-0,19	-0,97	-1,32	-1,74	-0,51	0,74	0,47	0,05	-0,20
Curtose	-0,17	0,51	0,13	0,67	0,75	1,79	3,37	0,64	-0,02	-0,33	1,53	0,48
K-S	0,13*	0,08*	0,08	0,08*	0,13*	0,14*	0,16*	0,07*	0,10*	0,08*	0,10*	0,10*
Annatto												
Average	1,05 *b*	14,87 *b*	33,64 *c*	46,67 *b*	2,81 *a*	3,16 *a*	94,64 *a*	32,37 *b*	1,01 *a*	383,86 *a*	320,14 *c*	296,00 *ab*
Medium	1,06	14,50	33,643	46,36	2,85	3,19	94,86	32,14	0,99	385,90	320,73	296,00
SD	0,09	20,36	2,706	3,81	0,24	0,11	2,33	3,53	0,40	51,56	34,42	48,64
CV (%)	8,14	3,03	8,04	8,17	8,63	3,45	2,46	10,92	39,72	13,32	10,65	16,43
Asymmetry	-0,70	0,62	-0,39	0,12	-0,83	-1,20	-0,66	0,89	0,74	0,45	0,01	-0,15
Curtose	0,53	1,14	1,01	1,80	0,33	1,30	0,20	1,99	-0,02	-0,51	-0,34	-0,83
K-S	0,07*	0,07*	0,04	0,08*	0,09*	0,12*	0,09*	0,10*	0,07*	0,12*	0,09*	0,11*
Cupuacu												
Average	1,14 *a*	13,39 *c*	23,24 *d*	34,75 *c*	2,59 *b*	3,04 *b*	93,74 *a*	20,72 *c*	0,50 *c*	284,69 *c*	418,06 *b*	297,25 *a*
Medium	1,14	12,82	23,165	33,86	2,60	3,05	94,05	20,05	0,48	286,70	415,20	303,20
SD	0,10	2,43	3,396	3,46	0,26	0,16	2,45	4,24	0,19	29,96	59,37	43,52
CV (%)	8,97	18,11	14,61	9,96	9,87	5,20	2,61	20,48	38,67	10,53	14,20	14,64
Asymmetry	-0,12	0,62	0,20	0,68	-0,68	-1,13	-0,76	0,53	0,34	-0,20	0,98	-0,74
Curtose	-0,60	0,18	-0,16	-0,02	0,85	1,02	0,79	-0,29	-0,79	0,31	1,29	0,22
K-S	0,08*	0,12*	0,06	0,11*	0,10*	0,15*	0,08*	0,091*	0,43*	0,06*	0,09*	0,10*
Forest												
Average	0,96 *c*	17,78 *a*	34,72 *b*	50,38 *a*	2,52 *bc*	2,94 *c*	93,67 *a*	36,53 *a*	0,62 *b*	238,88 *a*	483,25 *a*	277,87 *b*

Medium	0,97	17,01	34,731	49,74	2,52	2,96	94,09	35,67	0,61	238,00	483,40	276,94
SD	0,09	4,14	3,458	3,39	0,31	0,26	2,66	5,73	0,24	24,09	45,85	39,81
CV (%)	9,60	23,28	9,96	6,74	12,33	8,91	2,83	15,7	39,08	10,08	9,54	14,33
Asymmetry	0,01	-0,11	-0,01	0,25	0,00	-0,91	-0,63	-0,03	0,43	0,21	-0,17	0,21
Curtose	0,19	1,38	-0,41	-0,55	-0,56	0,47	-0,12	-0,28	-0,34	0,13	-0,35	0,00
K-S	0,07*	0,09*	0,08*	0,15*	0,15*	0,11*	0,11*	0,08*	0,71*	0,06*	0,08*	0,10*

Note: Means followed by the same lowercase letter in the column do not differ by Tukey test ($p < 0.05$).
SD: standard deviation; CV: coefficient of variation (%); K-S: Kolmogorov-Smirnov normality test. * Significant at 5% probability; Ds: soil density; MaP: macroporosity; MiP: microporosity; TPV: total porosity; DMG: geometric mean diameter; WAD: weighted mean diameter; IEA: Aggregate Stability Index; HG: gravimetric Humidity: RPS: soil resistance to penetration;

Table 3. Mean test and descriptive statistics of the physical attributes in the depth of 0.10-0.20 m for the areas with different uses in the south of Amazonas.

Descriptive statistics	Sd	MaP	MiP	TPV	GAD	WAD	IEA	HG	SRP	Sand	Silt	Clay
	g cm^{-3}	------ m^3 m^{-3}------			----- mm -----		----- % -----		MPa	----- g kg^{-1} -----		
Guarana												
Average	1,13 *b*	11,31 *b*	36,88 *a*	45,77 *a*	2,09 *b*	2,72 *bc*	89,47 *c*	33,14 *a*	0,69 *b*	361,48 *b*	434,92 *b*	203,60 *c*
Medium	1,12	3,85	36,958	6,95	2,05	2,72	90,31	6,13	0,68	360,10	435,40	204,00
SD	0,06	34,04	3,993	15,19	0,43	0,27	5,38	18,50	0,30	40,65	23,63	39,11
CV (%)	5,66	11,09	10,83	46,86	20,62	9,87	6,02	32,14	43,42	11,18	5,43	19,19
Asymmetry	0,28	0,18	-0,62	-1,03	-0,15	-0,38	-1,08	-0,21	1,60	0,76	0,19	-0,36
Curtose	-0,33	0,24	0,95	1,90	-0,50	-0,29	0,84	1,97	7,36	0,03	0,56	-0,65
K-S	0,09*	0,06*	0,10*	0,10*	0,06*	0,06*	0,14*	0,08*	0,09*	0,10*	0,08*	0,10*
Annatto												
Average	1,06 *c*	12,61 *b*	32,52 *c*	43,41 *b*	2,62 *a*	3,03 *a*	92,83 *a*	31,22 *b*	0,69 *b*	380,31 *a*	405,28 *c*	214,41 *b*
Medium	1,06	12,43	32,521	43,48	2,67	3,09	93,80	31,11	0,68	380,30	409,14	211,20
SD	0,09	3,33	2,349	3,89	0,27	0,18	3,48	2,77	0,30	53,63	54,32	48,07
CV (%)	8,90	26,42	7,22	8,96	10,46	5,79	3,75	8,88	43,42	14,10	13,40	21,76
Asymmetry	0,01	0,14	-0,09	0,09	-0,69	-1,16	-1,04	0,70	1,60	0,29	-0,01	0,03
Curtose	0,00	-0,25	-0,21	1,72	0,75	0,90	0,64	1,55	7,36	-0,43	-0,42	-0,43
K-S	0,05*	0,06*	0,04	0,09*	0,11*	0,16*	0,15*	0,09*	0,19*	0,07*	0,08*	0,12*
Cupuacu												
Average	1,16 *a*	12,64 *b*	10,58 d	46,18 *a*	2,07 *b*	2,62 *c*	90,92 *bc*	31,01 *b*	0,77 *a*	279,30 *c*	418,40 *bc*	302,30 *a*
Medium	1,18	3,23	10,511	3,99	2,07	2,66	91,83	3,53	0,75	278,40	419,50	295,20
SD	0,10	25,53	3,142	8,63	0,39	0,35	3,69	11,39	0,29	26,62	44,49	35,74
CV (%)	8,63	12,49	29,71	45,77	18,67	13,34	4,06	30,59	37,97	9,53	10,63	11,82
Asymmetry	-0,22	0,48	0,57	-0,06	-0,28	-0,67	-1,21	0,49	0,04	0,40	0,06	0,31
Curtose	1,11	-0,20	-0,17	-0,13	-0,70	-0,28	1,30	0,35	-0,66	-0,10	0,50	-0,05
K-S	0,12*	0,13*	0,14*	0,09*	0,09*	0,10*	0,13*	0,09*	0,07*	0,06*	0,07*	0,10*
Forest												
Average	1,02 *c*	16,47 *a*	33,36 *b*	47,64 *a*	2,15 *b*	2,75 *b*	91,86 *ab*	32,63 *ab*	0,65 *b*	241,16 d	467,04 *a*	291,80 *a*
Medium	1,03	16,34	33,398	47,40	2,15	2,75	92,65	32,76	0,65	240,98	466,22	292,00

SD	0,09	4,28	2,741	4,75	0,46	0,33	3,93	2,04	0,25	27,20	39,42	32,46
CV (%)	9,26	25,97	8,21	9,98	21,59	11,90	4,28	6,24	38,01	11,28	8,44	11,22
Asymmetry	-0,09	0,67	-0,33	-0,27	-0,07	-0,42	-0,65	0,50	-0,21	0,42	0,25	-0,80
Curtose	0,83	0,69	1,48	0,89	-0,86	-0,61	-0,14	0,49	-0,97	0,15	0,53	1,24
K-S	0,06*	0,13*	0,08*	0,09*	0,07*	0,09*	0,09*	0,11*	0,05*	0,09*	0,06*	0,15*

Note: Means followed by the same lowercase letter in the column do not differ by Tukey test ($p < 0.05$).
SD: standard deviation; CV: coefficient of variation (%); K-S: Kolmogorov-Smirnov normality test. * Significant at 5% probability; Ds: soil density; MaP: macroporosity; MiP: microporosity; TPV: total porosity; DMG: geometric mean diameter; WAD: weighted mean diameter; IEA: Aggregate Stability Index; Ug: gravimetric unit: RPS: soil resistance to penetration;

Table 4. Pearson correlation of soil physical attributes in areas under forest conversion in cultivated areas in southern Amazonia.

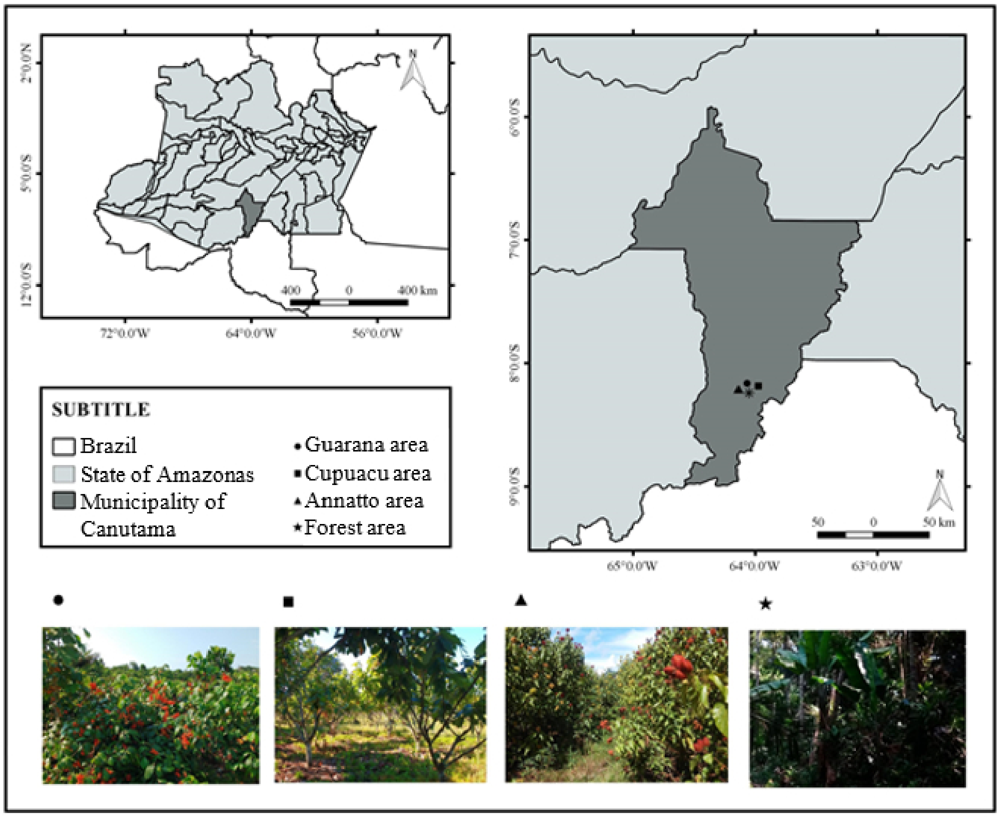
Attributes	Sd	MaP	MiP	TPV	HG	GAD	WAD	IEA	Sand	Silt	Clay	SRP
Sd	1,00	-0,56**	0,16**	-0,22**	-0,48**	-0.08ns	-0.08ns	-0,13*	0,48**	-0,51**	-0.06ns	0,59**
Macro		1,00	-0,41**	0,20**	0.09ns	0.02ns	-0.02ns	0.06ns	-0,42**	0,45**	0.08ns	-0,57**
Micro			1,00	0,70**	0,66**	0,22**	0,19**	0,22**	0,32**	-0,32**	-0,12*	0,45**
TPV				1,00	0,71**	0,23**	0,20**	0,23**	0,13*	-0.08ns	-0.09ns	0,14*
HG					1,00	0,21**	0,15**	0,30**	-0,13*	0,12*	-0.004ns	-0.04ns
GAD						1,00	0,82**	0,81**	0.10ns	-0,11*	0.012ns	0.10ns
WAD							1,00	0,62**	0,18**	-0,18**	-0.05ns	0,13*
IEA								1,00	-0,16**	0.10ns	0,21**	-0.01ns
Sand									1,00	-0,87**	-0,50**	0,60**
Silt										1,00	0,11*	-0,59**
Clay											1,00	-0,18**
SRP												1,00

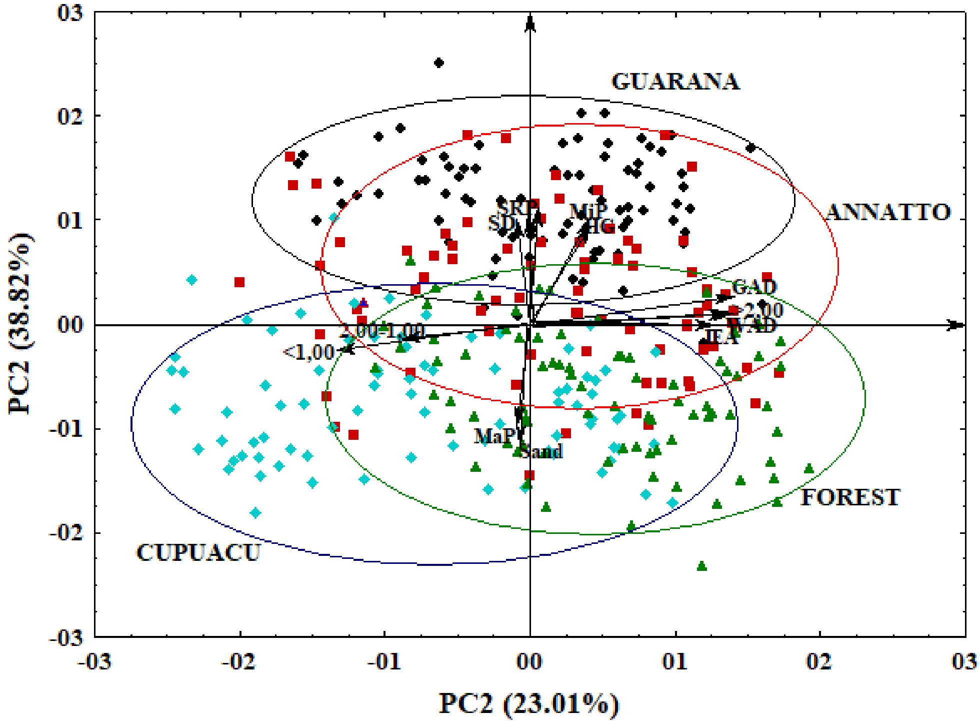
Note: * = significant at the 5% probability level; ** = significant at the 1% probability level; ns = not significant.

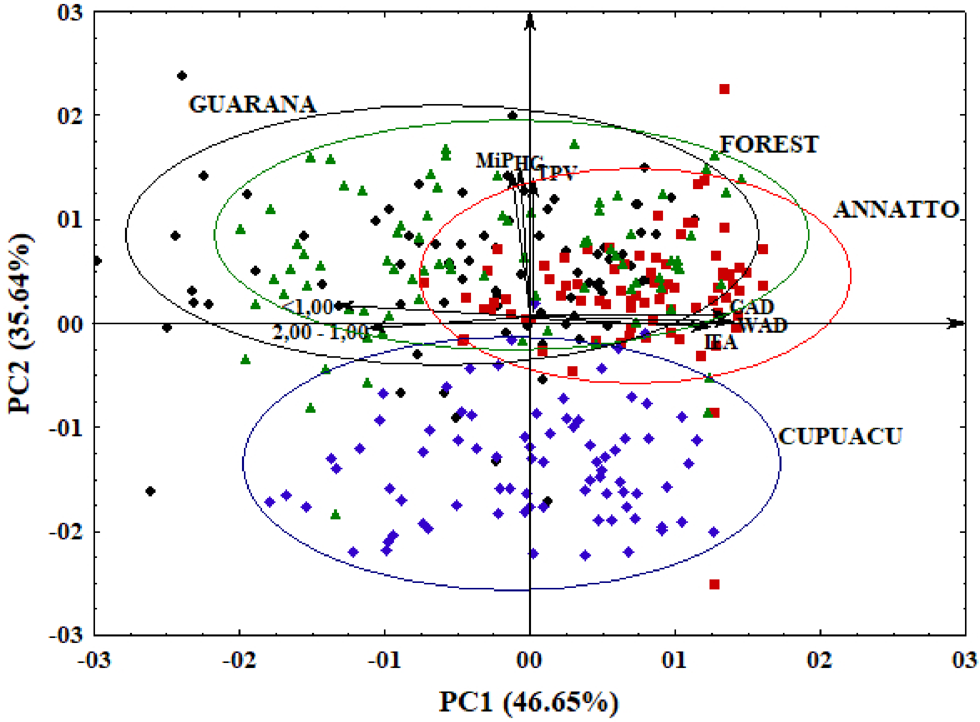
Table 5. Correlation between each principal component of the analyzed variables of the physical attributes of the soil in the three depths studied corresponding to the areas under conversion of forest in cultivated areas in the South of Amazonas - AM.

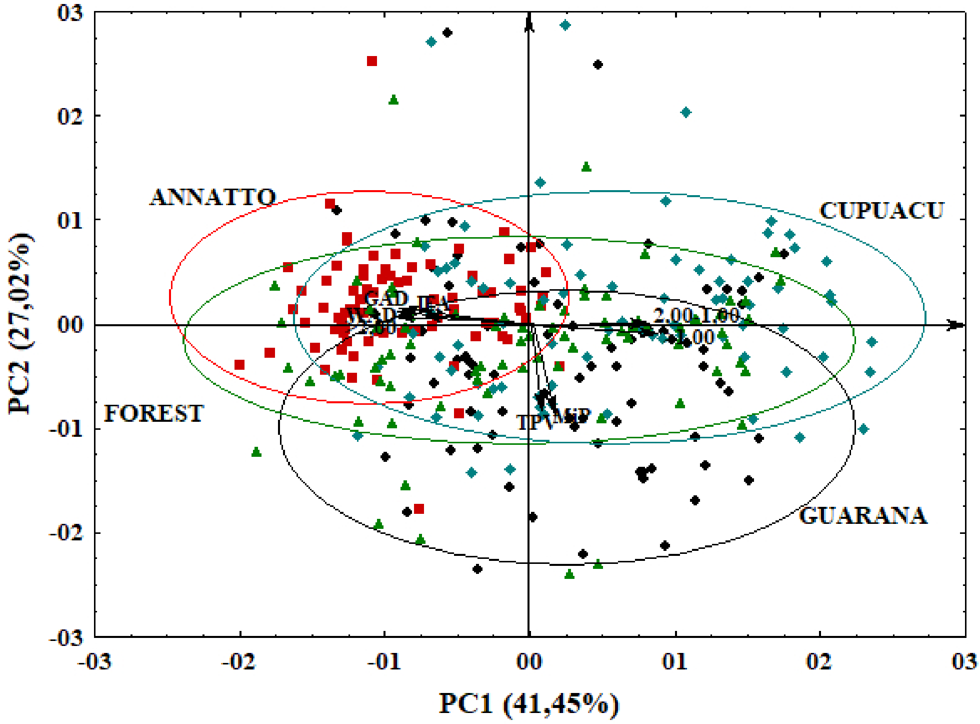
Attribute	Depths					
	0.00-0.05 m		0.05-0.10 m		0.10-0.20 m	
	PC1	PC2	PC1	PC2	PC1	PC2
SD	-0.05	0.67*	•••••	•••••	•••••	•••••
MaP	-0.06	-0.65*	•••••	•••••	•••••	•••••
MiP	0.28	0.69*	-0.08	0.95*	0.17	-0.86*
TPV	•••••	•••••	0.02	0.91*	0.08	-0.83*
GAD	0.93*	0.06	0.94*	-0.03	-0.93*	0.10
WAD	0.93*	0.16	0.93*	-0.02	-0.94*	0.06
Class >2,00	0.91*	0.06	0.92*	0.00	-0.91*	0.03
Class 1,00-2,00	•••••	•••••	-0.75*	-0.07	0.82*	0.01
Class <1,00	-0.89*	-0.16	-0.89*	0.07	0.89*	-0.08
IEA	0.84*	-0.02	0.82*	-0.04	-0.74*	0.09
HG	0.27	0.63*	0.04	0.95*	-0.08	-0.95*
SRP	0.00	0.71*	•••••	•••••	•••••	•••••
Sand	0.04	0.74*	•••••	•••••	•••••	•••••
Silt	-0.05	-0.78*	•••••	•••••	•••••	•••••
Clay	•••••	•••••	•••••	•••••	•••••	•••••
variance explained (%)	35.03	26.81	46.42	35.87	40.81	27.67

Sd: density; MaP: macroporosity; MiP: microporosity; TPV: total porosity; GAD: geometric average diameter; WAD: weighted average diameter; IEA: Aggregate Stability Index; Ug: gravimetric unit: SRP: soil resistance to penetration; HG: Gravity humidity; PC1 and PC2: principal component 1 and 2.


2°0.0'N
5°0.0'S
12°0.0'S
72°0.0'W
64°0.0'W
56°0.0'W
400 0 400 km
N
6°0.0'S
7°0.0'S
8°0.0'S
9°0.0'S
65°0.0'W
64°0.0'W
63°0.0'W
50 0 50 km
SUBTITLE
Brazil
State of Amazonas
Municipality of Canutama
Guarana area
Cupuacu area
Annatto area
Forest area


GUARANA
ANNATTO
FOREST
CUPUACU
SRP
SD
MiP
HG
GAD
>2,00
WAD
IEA
2,00-1,00
<1,00
MaP
Sand
PC2 (38.82%)
PC2 (23.01%)
03
02
01
00
-01
-02
-03


GUARANA
FOREST
ANNATTO
CUPUACU
MiP
HC
TPV
<1,00
2,00 - 1,00
CAD
WAD
IEA
PC1 (46.65%)
PC2 (35.64%)
03
02
01
00
-01
-02
-03


ANNATTO
CUPUACU
FOREST
GUARANA
PC2 (27,02%)
PC1 (41,45%)
03
02
01
00
-01
-02
-03
-03
-02
-01
00
01
02
03