Environmental Earth Sciences (2020) 79:251
https://doi.org/10.1007/s12665-020-08948-x

ORIGINAL ARTICLE

Physical attributes and organic carbon in soils under natural and anthropogenic environments in the South Amazon region

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Received: 20 March 2019 / Accepted: 27 April 2020 / Published online: 21 May 2020

Abstract
The transformation of natural Amazonian environments into production systems, mainly related to agriculture and livestock, is considered the most frequent anthropic activity in the region, which can cause significant changes in physical attributes and soil organic carbon. On the other hand, the proper development of the plants depends basically on the quality of the soil, which is directly related to its attributes. Thus, the objective of this study was to evaluate the physical attributes and organic carbon of the soil in natural environments and in anthropic uses located in the southern region of Amazonas. Samples were collected at four spots in three depths (0.00–0.05 m, 0.05–0.10 m, 0.10–0.20 m), totalling 108 samples. The organic carbon has a positive correlation with silt, geometric mean diameter, weighted mean diameter and aggregates > 2 mm, and negative with soil and clay density. The environments with native forest 1, pasture and agroforestry are characterized by higher values of organic carbon, silt, geometric mean diameter, weighted average diameter and aggregates > 2 mm, while native forest 3, native forest 4 and açaí are characterized by higher values of clay and aggregates clay and aggregates between 2–1 mm and < 1 mm.

Keywords Soil structure · Aggregate stability · Amazonian environments · Carbon stock

Introduction

One of the great highlights of the Amazon biome is its great potential in biodiversity, where it has an extensive forest, which houses a fauna and flora, and becomes a great attraction for researchers in the search for the characterization of the dynamics of this ecosystem and can thus gauge its various characteristics. as well as extraction of alternative raw materials for the various industrial activities (Melo et al. 2017).

The Amazon region is located in the northern part of South America, with about 6 million km^2 (Vale Júnior et al. 2011). It has the largest tropical forest in the world, being the largest reservoir of biodiversity on the planet and where natural environments still persist. A member of the Amazon region, the southern Amazon region occupies approximately 474,021 km^2 of its total area, equivalent to 30% of the state of Amazonas. Among the municipalities that make up the southern region of Amazonas, Humaita is highlighted as the municipality where the junction between the BR 230 and BR 319 occurs, serving as support for travelers from various regions of the country and abroad.

Until the mid-1960s, the exploitation of Amazonian resources was extractive. However, afterward, exploration intensified to integrate the region into the productive and economic process of the country. Livestock farming, one of the most developed economic activities in land use, contributed to the large deforestation and to the cultivated pastures for cattle rearing, and agriculture managed with cutting and burning, causing negative environmental impacts, sometimes even irreversible (Dutra et al. 2000; Rivero et al. 2009).

With the population increase there is a great concern about the world production of food to meet this need (Arraes et al 2012), so it is opted for the advance of agriculture over natural forests (Silva et al. 2015), ie conversion of a natural

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environment into In this area of cultivation, with this activity comes the doubt of the adverse environmental impacts caused to these environments, mainly related to biodiversity, considering that changes in the environment cause loss of vegetation, change in animal habits, as well as changes in soil attributes, however, At the level of degradation there is still little information (Domingues et al. 2017).

The inadequate use of the soil for agricultural practices directly affects the physical quality of the soil, causing significant modifications in the organic matter content and degradation of soil attributes (Silva et al. 2005; Sá et al. 2010). Thus, knowledge of changes in soil attributes caused by the various anthropogenic uses provides aid for the adoption of management practices that allow to increase the yield of the productive process, with the conservation of the environments, ensuring that future generations can use these environments way we use today, that is, to provide "sustainable development". In this sense, the evaluation of soil attributes in natural and anthropized environments becomes necessary to find subsidies and propose management techniques that aim to minimize and even inhibit possible environmental changes.

Despite the great importance of multivariate statistical methods for interpretations of variations in soil attributes, few studies have used this tool since most use univariate statistical methods (Silva et al. 2010b). However, some studies have applied multivariate techniques to evaluate soil variables and found satisfactory results (Campos et al. 2012b, Pragana et al. 2012; Campos et al. 2013; Oliveira et al. 2013; Mantovanelli et al. 2015, Soares et al. 2016, Cunha et al. 2017).

The proposal of the use of multivariate statistics is justified by having a greater capacity to describe the intra and interdependence relations in agricultural systems (Marques, 2009). With the multivariate analysis, it is possible to explain the maximum correlation between the variables and find out which ones contribute most to the evaluation of soil quality. In the simultaneous analysis of any information, this technique becomes the best tool, allowing to obtain data and interpretations that could not be perceived with the use of univariate statistical analysis (Cruz and Regazzi 2001). Therefore, the objective of this research was to evaluate the physical attributes and organic carbon of soils in natural environments and anthropic uses in the southern region of Amazonas.

Material and methods

The study was carried out in five rural properties located in the south of Amazonas, more precisely in the municipality of Humaitá (Fig. 1). In these properties, four environments with natural characteristics (native forests—NF) were selected, serving as natural environments, numbered from 1 to 4 for differentiation (NF1, NF2, NF3 and NF4) and also five environments with different anthropic uses, such as pasture—P (natural environment: NF1), agroforestry—AF, cassava—C, açaí—A and reforestation—RF (chart 1).

The environment with pasture (P) is formed with *Brachiaria brizantha* (cv. Marandu) and several tucumã plants (*Astrocaryumaculeatum*) scattered over the pasture, with about 20 years of implantation, maintained with a low stocking of cattle. The environment with agroforestry (AF) where species such as Andiroba (*Carapaguianensis*), Cupuaçu (*Theobromagrandiflorum*), açaí (*Euterpe oleracea*), Brazil *nut* (*Bertholletia excelsa*), cocoa (*Theobromacacao*), pupunha (*Bactrisgasipaes*) and tucumã (*Astrocaryumaculeatum*). The AF environment has access to small animals (pigs and birds), created in an extensive way. The environment cultivated with cassava (C) (*Manihotesculenta*) is with approximately two years of cultivation, where the practice of harrowing occurred before planting. The environment with açaí (A) (*Euterpe oleracea*) cultivation with the beginning of cultivation in the year 2010, the area has anirrigation system and frequently receives cover fertilization. The environment with reforestation (RF) being implanted in 2004 for the cultivation of Teak (*Tectonagrandis* L.), Mahogany (*Swieteniamacrophylla* King.), Andiroba (*Carapaguianensis* Aubl.), Jenipapo (*Genipa Americana* L.) and *Brachiariabrizantha* (Marandu cv.) pasture between the lines of these species, characterized at the time as a silvopastoral system. However, currently, the environment does not have pasture, for this reason, was identified as an environment with reforestation.

The soil source material from the region comes from the alluvial sediments, which are chronologically derived from the Holocene (BRASIL 1978). The climate in Amazonas is equatorial (hot and humid), with relative air humidity ranging from 76 to 89% and average temperatures of 22.0–31.7 ºC, having two well defined seasons: winter, considered the period of the rainfall and summer, dry season or less rainy season (Maia and Marmos 2010).

Soil samples were collected in nine environments, four natural environments (forest fragments) and five environments in different anthropic uses (pasture, agroforestry, cassava, acai, and reforestation). The surveys were carried out between November 2016 and March 2017. Thus, trenches were opened at depths of 0.00–0.05, 0.05–0.10 and 0.10–0.20 m, collecting soil blocks with a minimally altered structure, packed in identified plastic bags, and collected samples with preserved structure, in duplicate, with the aid of volumetric cylinders (69 cm^3), and packed in a thermal box so as not to alter the structure of the soils sampled. For each study environment, four replications were performed at randomly selected points. At the end of the sampling, 108 lightly altered soil samples (soil clods) and 108 soil samples were obtained, in duplicate in each layer

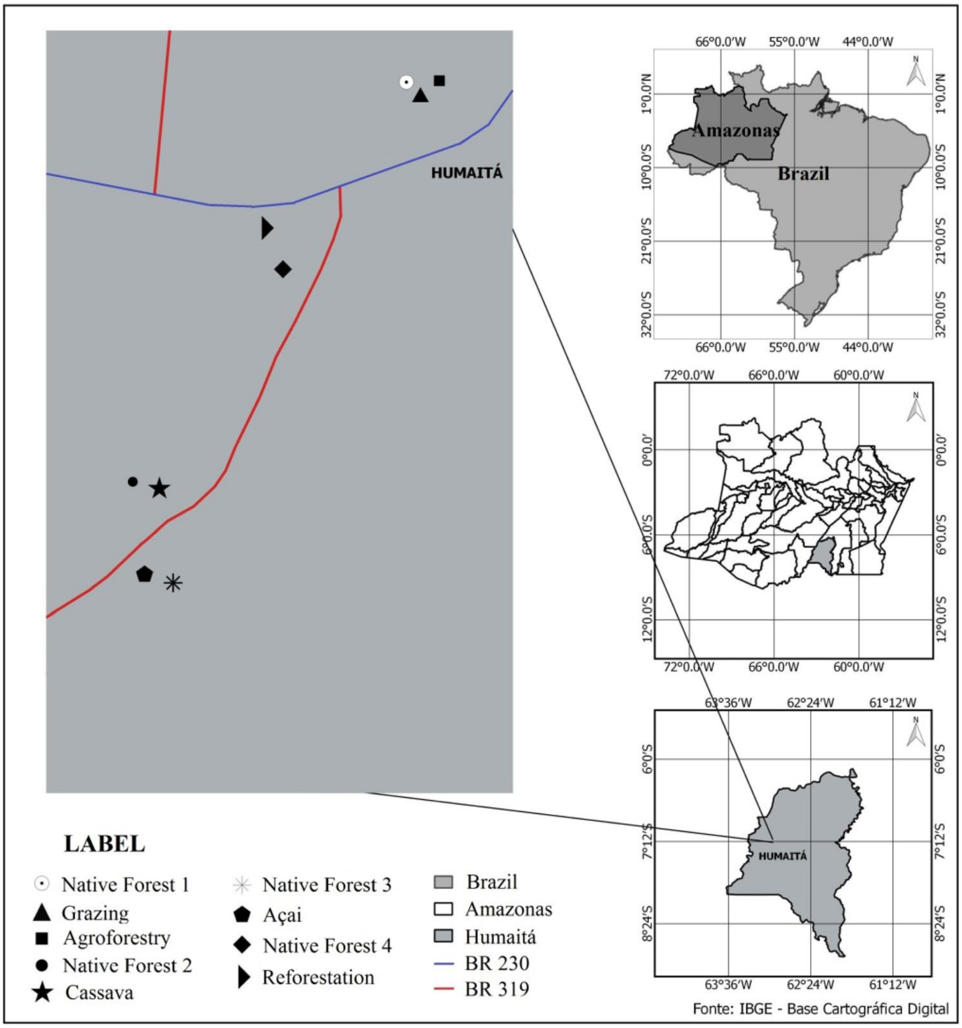

Fig 1. Location of the environments used in the study, in Humaitá, Amazonas.

(to analyze the best of the two), with a preserved structure (volumetric cylinders), being sent to the laboratory where the physical and organic carbon analyzes were carried out. The collect points had their coordinates registered with the aid of a Garmin Global Positioning Satellite (GPS) equipment (GPSmap 64S).

The textural (sand, silt and clay) components were determined by the pipette method. Basically, the time for vertical displacement in the soil suspension with water was fixed after the addition of chemical dispersant (NaOH 0.1N) and slow stirring for 16 h in Wagner-type mechanical stirrer apparatus, with rotation adjusted to about 50 rpm. A 50 ml volume of the suspension was pipetted to determine the clay which was weighed after oven drying. The coarse fractions (fine and coarse sand) were separated by sieving, oven dried and weighed to obtain their bulk fractions. The silt was obtained by difference of the other fractions in relation to the original sample of 20 g of soil (Embrapa 2011).

For the determination of soil density (SD), macroporosity (MAP) and microporosity (MIP) and total porosity (TP), the samples collected in volumetric rings were saturated by gradual elevation until two-thirds of the ring's height from a water slide on a plastic tray. After saturation, the seeds will be weighed and taken to the stress table to determine the soil MIP, being subjected to a tension of − 0.006 MPa. After reaching equilibrium at a matrix potential of − 0.006 MPa, the samples will be re-weighed and then the sample will go to the penetrograph where the penetration resistance of the soil (SRP) was determined, finally the samples were taken to the greenhouse at 105 °C for 16 h, and after removal and cooling in desiccator, these are weighed again, and then obtaining the data will be determined to SD and TP, by the volumetric ring method, and the MAP was determined by the difference between VTP and MiP (Embrapa 2011).

To determine the stability of aggregates, soil blocks with the preserved structure were used, air dried, fragmented into smaller clusters manually and passed through a 9.51 mm mesh screen, using the aggregates retained in the sieve of 4.76 mm. Separation and stability of the aggregates were determined according to Kemper and 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 were placed in contact with water on the 2.0 mm sieve and subjected to vertical shaking in Yoder apparatus (Solotest, Bela Vista, São Paulo, Brazil) for 15 min and with 32 oscillations per minute. The material retained in each class of the sieves was placed in an oven at 105 ºC, and then measured the respective masses on a precision digital scale (Embrapa 2011).

The results were expressed as a percentage of the aggregates retained in each of the sieve classes and the stability of the aggregates evaluated by the weighted average diameter (WAD) obtained by the formula proposed by Castro Filho et al (1998), and the geometric mean diameter (GMD), according to Maia and Marmos (2010), cited by Alvarenga et al (1986), according to the equations:

$$\mathrm{WAD} = \frac{\sum_{i=1}^{N} n_i D_i}{\sum n_i} \tag{1}$$

$$\mathrm{GMD} = 10^{\frac{\sum_{i=1}^{N} n_i log D_i}{\sum n_i}} (2) \tag{2}$$

where n_i is the percentage of aggregates retained in a given sieve, D_i is the average diameter of a given sieve and N is the number of sieve classes.

For the determination of soil density (SD), macroporosity (MAP) and microporosity (MIP), total porosity (TP) and soil gravimetric moisture (SM), samples collected in volumetric cylinders were prepared and saturated with a gradual elevation of a water slide, up to two-thirds the height of the ring, in a plastic tray. After saturation, the samples were weighed on a digital scale and taken to the tension table to determine the soil MIP, being subjected to a matrix potential of − 0.006 MPa (Embrapa 2011).

After reaching 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 made using an electronic bench pedometer (MA-933, Marconi, SP, BR), with a constant velocity of 0.0667 mm s^{-1}, 4 mm diameter base cone and 30° semiangle, receiver and interface coupled to a microcomputer to record the readings.

Afterward, the samples were taken to the oven at 105 ºC for determination of the soil moisture (SM), SD and MAP by the volumetric cylinder method, and the TP was determined by the sum of MAP with MIP (Embrapa 2011).

Total organic carbon (OC) was determined by the Walkley–Black method, modified by Yeomans and Bremner (1988). The organic matter is determined by the OC product with 1724 (Embrapa 2011). The carbon stock (CS) is defined by the equation below:

$$\mathrm{CS} = Sd \times h \times \mathrm{COT} \tag{3}$$

where: CS = carbon stock (Mg ha^{-1}); Sd = soil density (g cm^{-3}); h is the thickness of the soil layer sampled (cm); COT = C content (%).

After the determination of the physical attributes and soil organic carbon, univariate and multivariate statistical analyzes were performed. The univariate analysis of variance (ANOVA) was used to compare attribute means individually using the Scott-Knott test at 5% probability, comparing all the environments and then comparing the environments in anthropic uses with their respective natural environments. These analyzes were conducted using a spreadsheet and ASSISTAT 7.7.

Then, the factorial analysis of the main components was performed to find statistical significance of the sets of soil attributes that more discriminate the study environments, obtaining as answer which are the environments whose attributes are most influenced by the anthropic action. These statistical analyzes were performed using the statistical software STATISTICA 7.0 (StatSolft 2004).

The adequacy of the factorial analysis was made by the KMO (*Kaiser–Meyer–Olkin)* measure, which evaluates the simple and partial correlations of the variables, and the *Bartlett* sphericity test, which is intended to reject the equality between the correlation matrix and identity. The extraction of the factors was done by the analysis of the main components (PCA), incorporating the variables that presented commonalities equal or superior to five (5). The choice of the number of factors to be used was made by the *Kaiser* criteria (factors that have eigenvalues greater than 1). To simplify the factorial analysis, orthogonal rotation (*varimax*) was performed and represented in a factorial plane of the variables and the scores for the main components. In the scatter plot of the PCA after *varimax* rotation, the scores were constructed with standardized values such that the mean is zero and the distance between the scores are measured in terms of the standard deviation. In this way, the variables in the same quadrant (1°, 2°, 3° and 4°) and closer to the dispersion graph of the PCA are better correlated. Likewise, scores attributed to the samples that are close and in the same quadrant are related to the variables of that quadrant (Burak et al. 2010).

Results and discussion

The environments with NF1, P and AF presented a silt franc texture, with sand contents varying between 11 and 21%, silt between 60 and 70% and clay between 16 and 24%, in the three depths (Table 1). The other environments presented a clay texture, with sand contents between 10 and 27%, silt between 20 and 47% and clay between 29 and 65%. In the depth of 0.00–0.05 m, there were no significant differences in the sand contents between NF4

Table 1 Soil texture (sand, silt and, clay) in natural environments and anthropic uses in the southern region of Amazonas, Brazil

Environments[a]	Depths (m)		
	0.00–0.05	0.05–0.10	0.10–0.20
Sand (g kg^{-1})			
NF_1	123f	120f	116e
P	209b	192b	162c
AF	154e	170c	147d
NF_2	125f	134e	158c
C	188c	176c	189b
NF_3	120f	110f	115e
A	166d	154d	151d
NF_4	195c	185b	192b
RF	269a	220a	206a
CV (%)	2.66	14.83	3.30
Silt (g kg^{-1})			
NF_1	699a	691a	670a
P	621b	618c	602b
AF	685a	659b	671a
NF_2	453c	426d	319d
C	424d	392e	294d
NF_3	421d	311h	239f
A	392e	316h	259e
NF_4	368f	352g	336c
RF	434d	364f	209g
CV (%)	3.48	1.69	1.55
Clay (g kg^{-1})			
NF_1	179f	189f	215f
P	170g	189f	237e
AF	161g	171g	181g
NF_2	421c	440d	523c
C	387d	432d	518c
NF_3	463a	580a	645a
A	442b	530b	590b
NF_4	438b	463c	472d
RF	297e	416e	585b
CV (%)	1.88	1.18	1.57

[a] *NF1* native forest 1, *P* pasture, *AF* agroforestry, *NF2* native forest 2, *C* cassava, *NF3* native forest 3, *A-acai NF4* native forest 4, *RF* reforestation. Means followed by the same letter in the column do not differ by Scott-Knott's test at 5% probability

and C, as they presented significantly similar averages, as did also between NF1, NF2 and, NF3. At the depth of 0.05–0.10 m, the environments with P and NF4 had similar values, as did C and AF and also as NF1 and NF3. For the depth of 0.10–0.20 m, the environments with NF4 and C were statically equal, as well as P and NF2, A and AF and also NF1 and NF3. The proximity to the texture values of these three environments (NF1, P and AF), besides being close environments, can be explained by having a direct relation of relief (CAMPOS et al. 2012a). Similar results were found by Martins et al. (2006) and Campos et al. (2012a), in studies carried out near this region.

The lowest clay fractions were in AF at all three depths. There were no significant differences between the environments with A and NF4 and between P and AF in the depth of 0.00–0.05 m, NF2 with C and NF1 with P in the depth of 0.05–0.10 m, and NF2 with C at the depth of 0.10–0.20 m. The high silt content is justified by the alluvial nature of the sediments that make up the original material (BRASIL 1978). According to Rosolen and Herpin (2008), which have already studied soils in the region, the occurrence of small depressions in soil topography favors the movement and deposition of thinner sediments into lower relief parts. According to Campos et al. (2012a) and Santos et al. (2012), in studies with soils in toposequences under alluvial terraces in the region of the middle Madeira river, found high levels of silt, with values close to 600 g kg^{-1}, corroborating that high levels of silt are common in the soils of the region.

In the comparison of the environments in anthropic uses with their respective natural environments (Table 1), it was verified that there were significant differences in the texture of most environments, with tendencies of increases in sand content and reduction of the finer particles in the most superficial layer. although the texture is considered a constant attribute in the medium and long term, variations such as those of the environments in anthropogenic uses can happen due to the natural action and, to a lesser extent, by human action, and there may be changes in the contents of clay, suggesting its vertical migration since this parameter is influenced by the texture and the organic carbon in the soil (Araújo et al., 2011; Reinert and Reichert 2006).

The majority of the environments presented SD greater than 1.50 g cm^{-3} (Table 2). The exception was for the environments with NF1, P, NF2, C, and, NF4 in the depth of 0.00–0.05 m and NF1 in the depths of 0.05–0.10 m and 0.10–0.20 m, which presented values lower than 1.50 g cm^{-3}. It can be seen from the data in Table 2 that most environments increased SD in relation to their natural environments, except for the environment with C that did not present significant differences in relation to NF2 in all depths, and the environment with A, which had no differences at depths of 0.05–0.10 and 0.10–0.20 relative to NF3. The increase in SD generally indicates an environment with greater resistance to root growth, reduction of aeration and reduction in soil hydraulic capacity. The decrease in SD values may be related to the increase of organic matter in the soil. In this way, the low soil density may be related to the high levels of organic carbon and of intense biological activity (fauna and roots), that construct canals, cavities and galleries in the subsoil (STEINBEISS et al. 2009; Soares et al. 2016).

In this study, the natural environments presented an increase of SD as the depth progressed (Table 2), with this

Table 2 Humidity, density and soil resistance to penetration in natural and anthropogenic environments in Humaita, Amazonas

Environments[a]	Depths (m)		
	0.00–0.05	0.05–0.10	0.10–0.20
Soil moisture (%)			
NF_1	37.45b	33.92a	31.62a
P	31.94c	29.02b	26.71b
AF	31.77c	30.67b	30.58a
NF_2	47.54a	35.77a	30.91a
C	36.06b	35.92a	31.04a
NF_3	37.62b	31.83b	29.64a
A	32.97c	30.18b	28.89a
NF_4	43.95a	36.91a	30.39a
RF	25.32d	23.66c	22.55b
CV (%)	8.74	9.25	11.60
Soil density (g cm^{-3})			
NF_1	1.26d	1.39c	1.43d
P	1.39c	1.52b	1.58c
AF	1.50b	1.60b	1.57c
NF_2	1.32d	1.57b	1.66b
C	1.33d	1.53b	1.69b
NF_3	1.57b	1.66a	1.75b
A	1.65a	1.76a	1.73b
NF_4	1.47c	1.52b	1.73b
RF	1.75a	1.76a	1.86a
CV (%)	5.50	5.62	4.67
Soil resistance to penetration (SRP)			
NF_1	1.01c	0.86c	0.73d
P	1.15b	1.30a	0.98c
AF	0.86d	0.84c	0.73d
NF_2	0.52f	0.62e	0.58e
C	0.22g	0.76d	1.05b
NF_3	0.64e	0.61e	0.83d
A	1.09b	0.98b	1.06b
NF_4	0.54f	0.55e	0.89c
RF	1.21a	0.90c	1.49a
CV (%)	5.81	6.40	7.34

[a] *NF1* native forest 1, *P* pasture, *AF* agroforestry, *NF2* native forest 2, *C* cassava, *NF3* native forest 3, A-acai; *NF4* native forest 4, *RF* reforestation. Means followed by the same letter in the column do not differ by Scott-Knott's test at 5% probability

understanding that this effect can occur naturally for all the environments studied. This is probably due to the pressures exerted by the upper layers on the lower ones, which cause their compression and reduction of porosity (Cunha et al. 2011). However, studies have already shown that SD has an increase due to its intense use coupled with mechanization and inadequate soil management, promoting the degradation of soil physical quality, commonly identified by the increase in compaction level (Soares, 1992; Marchão et al. 2009; Collares et al. 2006; Bergamin et al. 2010; Soares et al. 2015), mainly in soils with high clay contents (SECCO et al. 2004), being a mechanical impediment for the growth of roots, affecting the development of the plants (Bergamin et al. 2010).

The highest SRP was recorded for the RF environment, followed by P and A, with significant differences in the three depths in relation to their natural environments (Table 2). There was a correlation with the increase in SD and MAP decrease. Increases in SRP and SD are associated with soil compaction, which is usually caused by the intensification of their uses and management. In the case of RF, there may be an association with the previous use of the environment as pasture, where animal traffic caused soil compaction in the most superficial layer. Despite this, these values are below the limit value of 2.0 MPa for compacted soils, defined by Tavares Filho and Tessier (2009). However, Soares et al. (2015), in TPA soils under pasture, verified values above 2.0 MPa in the depth of 0.00–0.05 mm, which, according to the authors, increased due to soil compaction by trampling animals.

A different effect of the other environments in AF and C, in the first layer, was observed in relation to their natural environments (NF1 and NF2, respectively), where there was a decrease in SPR, probably due to the increase in sand content and the development of roots of the plants in the first case, and in the second case, because of the use of harrowing before planting the cassava, which breaks the surface layer of the soil making it less compact. The increase of the SPR for the environment with C was associated to the increase of the MAP in the depth of 0.00–0.05 m, a fact that is not observed in the 0.10–0.20 m layer, in which the increase occurs of the SPR. According to Silva et al. (2005), soil tillage usually promotes a temporary increase in macroporosity. This fact may indicate the onset of the phenomenon called "foot-of-grid", where the most superficial layer of the soil is revolved and, at the same time, the counterbalance below forces and compacts the deeper layers, very common where this type is practiced of management.

MAP values lower than 0.10 m^3 m^{-3}, such as those occurring in the three depths in NF 3 and A, mainly in AF, NF^{-4} and RF (0.00–0.05 m), in NF 2 (0.05–0.10 m) and in NF2, C and NF4 (0.10–0.20 m) (Table 3) indicate critical values with probable limitations to soil aeration in wetter times (Baver et al. 1972; Pagliai et al. 2003; Bergamin et al. 2010). According to Feng et al. (2002), values equal to or very close to that in clayey soils may already cause inhibition to the adequate supply of oxygen to the plants, being ideal values higher than 0.10 m^3 m^{-3} of MAP. According to Lima et al. (2007), soils considered ideal have values equal to or greater than 0.50 m^3 m^{-3} of total porosity, in which the microporosity would oscillate between 0.25 and 0.33 m^3 m^{-3} and the macroporosity between 0.17 and 0.25 m^3 m^{-3}. Adverse conditions of TP are found in environments with AF, A and

Table 3 Macroporosity, microporosity and total porosity in natural environments and anthropic uses, in the southern region of Amazonas, Brazil

Environment[a]	Depths (m)		
	0.00–0.05	0.05–0.10	0.10–0.20
Macroporosity (m^3 m^{-3})			
NF$_1$	0.15c	0.12a	0.12a
P	0.13d	0.10b	0.10b
AF	0.08e	0.12a	0.12a
NF$_2$	0.18b	0.08c	0.08c
C	0.23a	0.10b	0.06d
NF$_3$	0.06f	0.08c	0.05e
A	0.05g	0.04d	0.06d
NF$_4$	0.07f	0.10b	0.04e
RF	0.04h	0.10b	0.05e
CV (%)	6.54	8.57	9.84
Microporosity (m^3 m^{-3})			
NF$_1$	0.39c	0.40a	0.39a
P	0.38c	0.38b	0.36b
AF	0.38c	0.38b	0.38b
NF$_2$	0.46a	0.44a	0.40a
C	0.33d	0.42a	0.42a
NF$_3$	0.47a	0.42a	0.41a
A	0.43b	0.42a	0.40a
NF$_4$	0.48a	0.43a	0.42a
RF	0.35d	0.34c	0.33b
CV (%)	5.15	4.67	7.22
Total porosity (m^3 m^{-3})			
NF$_1$	0.54b	0.52a	0.51a
P	0.51c	0.48b	0.46b
AF	0.46d	0.50a	0.50a
NF$_2$	0.64a	0.52a	0.48b
C	0.56b	0.52a	0.48b
NF$_3$	0.53c	0.50a	0.46b
A	0.48d	0.46b	0.46b
NF$_4$	0.55b	0.53a	0.46b
RF	0.39e	0.44c	0,38c
CV (%)	4.25	6.03	3.71

[a] *NF1* native forest 1, *P* pasture, *AF* agroforestry, *NF2* native forest 2, *C* cassava, *NF3* native forest 3, *A* acai, *NF4* native forest 4, *RF* reforestation. Means followed by the same letter in the column do not differ by Scott-Knott's test at 5% probability

Table 4 Geometric mean diameter and weighted mean diameter of soil aggregates in natural environments and anthropic uses in the southern region of Amazonas, Brazil

Environment[a]	Depths (m)		
	0.00–0.05	0.05–0.10	0.10–0.20
Geometric mean diameter (mm)			
NF$_1$	2.78b	1.82d	0.74e
P	2.72b	2.49a	2.18a
AF	2.99a	2.60a	1.57c
NF$_2$	2.67b	2.02c	1.31d
C	2.27d	2.30b	2.06b
NF$_3$	1.87f	0.53f	0.54f
A	2.03e	1.06e	0.79e
NF$_4$	1.82f	0.94e	0.46g
RF	2.46c	1.77d	1.31d
CV (%)	3.72	5.69	4.12
Weighted mean diameter (mm)			
NF$_1$	3.21a	2.60b	1.41d
P	3.17b	3.02a	2.79a
AF	3.26a	3.11a	2.41b
NF$_2$	3.15b	2.84b	2.32b
C	2.98c	2.94a	2.82a
NF$_3$	2.69e	1.50e	1.43d
A	2.88d	2.16c	2.08c
NF$_4$	2.77e	1.90d	1.25d
RF	3.13b	2.73b	2.04c
CV (%)	2.13	6.27	8.63

[a] *NF1* native forest 1, *P* pasture, *AF* agroforestry, *NF2* native forest 2, *C* cassava, *NF3* native forest 3, *A* acai, *NF4* native forest 4, *RF* reforestation. Means followed by the same letter in the column do not differ by Scott-Knott's test at 5% probability

RF, in the depth of 0.00–0.05 m, and the environments with P, A and RF in the depth of 0.05–0.10 m. In the depth of 0.10–0.20 m only the environments with NF1 and AF had TP equal to or greater than 0.50 m^3 m^{-3} (Table 4).

In Table 3, it was observed that the environment with RF was the one that presented the greatest difference of TP in relation to its natural environment (NF4), before the other environments, probably because of the influence of trampling of animals in the period when it was used in the silvopastoral system. The reduction of the total pore volume in pasture areas may be a reflection of the reduction of macroporosity, promoting a possible increase in soil density and microporosity, as well as a possible decrease in water infiltration rate, especially in the more superficial layer (Salton et al. 2002; Giarola et al. 2007; Goulart et al. 2010).

For the smaller aggregates (< 1 mm), the highest percentage was found in the environment with NF 3 (33.94%) and the lowest with AF (2.91%) in the upper layer. At the depth of 0.05–0.10 m, the highest and the lowest percentage continued with the same environments, with 58.90% for NF 3 and 7.49% for AF. In the depth of 0.10–0.20 m, the highest value was in the environment with NF 4 (70.02%) and the lowest value was in the environment with C (16.66%). The surface horizons are usually characterized by the rounded granular structure that presents a hierarchy in which aggregates > 2 mm are composed of smaller aggregates (Bronick and Lal 2005). In Table 5, it was clear that the percentage of aggregates > 2 mm has a downward trend in depth, while aggregates < 1 mm tend to increase with in-depth

Table 5 Stability of aggregates in natural environments and anthropic uses in the southern region of Amazonas, Brazil

Environments[a]	Depths (m)		
	0.00–0.05	0.05–0.10	0.10–0.20
>2 mm (%)			
NF$_1$	95.30a	69.85d	25.70e
P	93.56b	86.80b	64.45b
AF	96.81a	91.06a	65.61b
NF$_2$	92.64b	80.53c	52.66c
C	86.42c	83.84b	78.68a
NF$_3$	61.93e	32.51g	29.45e
A	83.30c	55.69e	42.64d
NF$_4$	74.39d	40.37f	21.75e
RF	91.42b	77.32c	50.49c
CV (%)	2.38	4.96	11.03
2–1 mm (%)			
NF$_1$	0.28g	6.42c	8.88b
P	0.90e	2.39g	5.13d
AF	0.28g	1.45h	4.84d
NF$_2$	1.28d	3.82e	10.53a
C	1.93c	3.12f	4.68d
NF$_3$	4.13b	8.59b	6.33c
A	1.78c	5.21d	6.84c
NF$_4$	5.34a	13.85a	8.23b
RF	0.69f	3.49e	7.60b
CV (%)	5.67	5.64	12.87
<1 mm (%)			
NF$_1$	4.42g	23.73d	65.42b
P	5.54f	10.81h	30.42e
AF	2.91h	7.49i	29.55e
NF$_2$	6.08f	15.65f	36.81d
C	11.65d	13.04g	16.64f
NF$_3$	33.94a	58.90a	64.22b
A	14.92c	39.10c	50.52c
NF$_4$	20.27b	45.78b	70.02a
RF	7.89e	19.19e	41.91d
CV (%)	4.00	1.94	6.38

[a] *NF1*—native forest 1, *P*—pasture, *AF*—agroforestry, *NF2*—native forest 2, *C*—cassava, *NF3*—native forest 3, *A*—acai; *NF4*—native forest 4, *RF*—reforestation. Means followed by the same letter in the column do not differ by Scott-Knott's test at 5% probability

Table 6 Organic carbon, organic matter and soil carbon stock in natural environments and anthropic uses in the southern region of Amazonas, Brazil

Environments[a]	Depths (m)		
	0.00–0.05	0.05–0.10	0.10–0.20
Organic carbon (g kg^{-1})			
NF$_1$	26.99b	18.19b	16.07b
P	26.30b	19.46b	18.74a
AF	28.84a	21.75a	16.57b
NF$_2$	20.34c	17.98b	11.31d
C	18.64c	18.71b	14.89c
NF$_3$	15.65d	11.55d	8.20f
A	16.85d	9.77e	8.81f
NF$_4$	18.62c	12.85c	10.09e
RF	10.63e	9.87e	8.42f
CV (%)	13.77	14.51	6.07
Organic matter (g kg^{-1})			
NF$_1$	46.53b	31.36c	27.69b
P	45.33c	33.54b	32.30a
AF	49.72a	37.49a	28.57b
NF$_2$	35.06d	31.00c	19.49d
C	32.12e	32.26c	25.24c
NF$_3$	26.98g	19.90e	14.13f
A	29.04f	16.84f	15.19f
NF$_4$	32.09e	22.16d	17.39e
RF	18.33h	17.01f	14.51f
CV (%)	13.77	14.51	6.07
Carbon stock (t ha^{-1})			
NF$_1$	167.87c	250.20d	227.42d
P	181.56b	295.87b	295.75a
AF	216.01a	348.63a	259.09b
NF$_2$	133.72d	277.07c	186.51e
C	123.95e	289.17b	245.69c
NF$_3$	121.76e	191.51e	142.94g
A	139.16d	171.36f	151.93g
NF$_4$	136.24d	194.46e	174.52f
RF	93.63f	172.64f	155.98g
CV (%)	11.60	2.70	3.68

[a] *NF1* native forest 1, *P* pasture, *AF* agroforestry, *NF2* native forest 2, *C* cassava, *NF3* native forest 3, *A* acai, *NF4* native forest 4, *RF* reforestation. Means followed by the same letter in the column do not differ by Scott-Knott's test at 5% probability

feed. The explanation for this is related to the OM content in soils, since there is a positive correlation between OM and aggregates >2 mm and negative between OM and aggregates <1 mm.

The conversion of natural environments to anthropogenic uses favored the alteration of the stability of aggregates in all study environments and in most of the studied depths, observing that there was a significant reduction in the larger aggregates (>2 mm) only in the environments with P and C, in the depth of 0.00–0.05 m. This decrease in aggregate size may have been due to decreased OM (Table 6) and a possible increase in SD (Table 2).

In Table 6, in the depths of 0.00–0.05 and 0.05–0.10 m, the AF environment presented the highest OC content, with 28.84 g kg^{-1} and 21.75 g kg^{-1}, respectively. At the depth of 0.00–0.05 m, the RF environment presented the lowest OC content (10.63 g kg^{-1}). In the 0.05–0.10 m depth, the environments with the lowest OC contents were A (9.77 g kg^{-1}) and RF (9.87 g kg^{-1}), without significant differences between them. At the depth of 0.10–0.20 m, the highest OC content was found in P (18.74 g kg^{-1}) and the lowest NF3 content (8.20 g kg^{-1}), followed by RF (8.42 g kg^{-1}) and A (8.81 g kg^{-1}), their means being considered equal by the test. Soils with less than 2% of organic carbon may be considered erodible and soil erodibility decreases linearly with OC content (LIU et al. 2010). Other literature considers the content of 40 g kg^{-1} as a critical limit for OM (EMBRAPA, 2013).

Only the environments with NF1, P and AF presented values higher than the critical limits for both OC and OM. The structural stability of the aggregates decreases when inadequate management practices result in the reduction of OM content for most soils (Paul et al. 2013). CS values were influenced by both OC and SD values. However, the environments with higher or lower CSs were the same with OC and OM. Thus, the same environments that presented higher or lower OC contents also presented higher or lower CS levels, that is, they were proportional.

In the comparison of the environments in anthropic uses with their natural environments, it was observed that there were significant differences in OC in AF at depths of 0.00–0.05 and 0.05–0.10 m in relation to NF1in A only in the depth of 0.05–0.10 m in relation to NF3, in P and C only in the depth of 0.10–0.20 m in relation to NF1 and NF2, respectively, and in RF in the three depths in relation to NF4. The maintenance of natural environments and environments with agroforestry depends on the recycling of the nutrients contained in litter and soil OM (Moreira and Malavolta 2004).

High OM contents maintain a well-structured soil with a balanced distribution of the particles (sand, silt, clay), with the appearance of pores where water and air are stored, constituting an ideal place for the development of the root system and plants. Probably, the increase of OM in the AF environment was due to the accumulation of plant residues (leaves, branches and roots) from the local plants, associated with ideal humidity and temperature, in the presence of decomposing microorganisms, resulting in the increase of OM content in this environment. environment. In the case of RF, the effect was contrary, since there was the suppression of the vegetation cover, with a higher percentage of vegetation, and the absence of anthropic uses (Siqueira Neto et al. 2009). insertion of a silvopastoral system, where there were soil erosion and pasture elimination due to inadequate management, promoting the low input of vegetal residues, which may justify the low levels of carbon in the soil. Silva et al. (2004) verified that pastures of low productivity favored the reduction of OM in the soil.

Soils with native forest present higher OM content, which gives them higher fertility due to the higher amount of organic residues (Morais et al. 2012). The greatest relation with OM is also due to the fact that it is directly associated with anthropic interference, without the use of agricultural implements and cultural practices, and does not degrade the stability of soil aggregates. According to Portugal et al. (2010) and Freitas et al. (2011), there is a decline in OM stock after the conversion of native forests into agricultural systems, as a consequence of increased soil erosion, mineralization of organic matter from the soil, and lower inputs of organic waste.

The highest values of carbon stocks (CS) were found in AF and P, in relation to the natural environment (NF1¬) and the other environments. According to Salimon et al. (2007), high values of carbon stock (CS) in pasture environments compared to native forest may occur due to the higher density and organic carbon content in these areas, and in some cases decreases in the first years of implantation, increasing in the following years until reaching values close to or greater than those existing before conversion, a process that probably occurred with the AF environment. Several studies have already verified a greater amount of CS in pasture environments in relation to the native forest.

Desjardins et al. (2004) and Araújo et al. (2011), verified that among these environments it is possible to observe that the evolution of the organic carbon of the soil obeys two simultaneous processes, one being the continuous mineralization of the carbon derived from the native vegetation due to the cycles of wetting and drying of the soil and the other to progressive incorporation of the carbon derived from the remnants of the crop introduced by the pasture, mainly by the grassroots. Souza et al. (2012), add that the high values of CS of pasture areas can occur in the presence of grasses that have an abundant root system and intense rhizosphere effect, where after their decomposition they release nutrients and contribute to the formation of soil OM, favouring their aggregation. Given these results, it is clear that the anthropic actions cause diverse alterations in the natural environments and that these alterations vary according to the uses and management affected by these environments.

The correlations between the studied soil attributes and the fractal dimension of the soil texture are presented in Table 7. According to Jakob (1999), the correlation analysis between variables shows the attributes that can be represented by others with a certain degree of correlation. tolerable information.

In Table 7, among the attributes that showed highest correlation coefficient values, the OC had a higher correlation ($p < 0.01$) positive with silt (0.73) GMD (0.71), WAD (0.71) and with aggregates > 2 mm (0.69), evidencing that the OC has an important contribution in the aggregation of the soil particles, also presenting a negative correlation ($p < 0.01$) with SD (– 0.74), clay (– 0.73) and aggregates < 1 mm (– 0.71), confirming the importance of OC in soil structuring. These results are in agreement with those obtained by Cunha et al. (2017), working with different uses

Table 7 Spearman's correlation coefficient (n = 108) between physical attributes, organic carbon and fractal dimension of texture in soils under natural environments and in anthropic uses, at a depth of 0.00–0.20 m in Humaitá, Amazonas

^{a}	CS	FS	Sand	Silt	Clay	SM	SD	MAP	MIP	TP	SRP	GMD	WAD	> 2 mm	2–1 mm	< 1 mm	OC	OC	CS
CS	–																		
FS	0.34^{c}	–																	
Sand	0.43^{c}	0.99^{c}	–																
Silt	− 0.44^{c}	− 0.27^{c}	− 0.30^{c}	–															
Clay	0.33^{c}	− 0.02	0.00	− 0.95^{c}	–														
SM	− 0.24^{b}	− 0.35^{c}	− 0.34^{c}	0.23^{b}	− 0.12	–													
SD	0.45^{c}	0.21^{b}	0.23^{b}	− 0.62^{c}	0.58^{c}	− 0.68^{c}	–												
MAP	− 0.40^{c}	− 0.06	− 0.08	0.48^{c}	− 0.48^{c}	0.31^{c}	− 0.75^{c}	–											
MIP	− 0.04	− 0.37^{c}	− 0.35^{c}	− 0.14	0.27^{c}	0.68^{c}	− 0.07	− 0.30^{c}	–										
TP	− 0.28^{c}	− 0,27^{c}	− 0.27^{c}	0.30^{c}	− 0.22^{b}	0.86^{c}	− 0.76^{c}	0.63^{c}	0.45^{c}	–									
SRP	0.18	0.22^{b}	0.22^{b}	0.05	− 0.12	− 0.52	0.42^{c}	− 0.43^{c}	− 0.20^{b}	− 0.59^{c}	–								
GMD	− 0.28^{c}	0.24^{b}	0.20^{b}	0.49^{c}	− 0.58^{c}	0.24^{b}	− 0.49^{c}	0.38^{c}	− 0.14	0.22^{b}	0.05	–							
WAD	− 0.29^{c}	0.23^{b}	0.19^{b}	0.50^{c}	− 0.59^{c}	0.23^{b}	− 0.47^{c}	0.37^{c}	− 0.15	0.21^{b}	0.06	0.99^{c}	–						
> 2 mm	− 0.30^{c}	0.25^{c}	0.20^{b}	0.49^{c}	− 0.57^{c}	0.26^{c}	− 0.47^{c}	0.37^{c}	− 0.13	0.23^{b}	0.04	0.96^{c}	0.97^{c}	–					
2–1 mm	0.21^{b}	− 0.18	− 0.13	− 0.46^{c}	0.53^{c}	− 0.20^{b}	0.38^{c}	− 0.28^{c}	0.13	− 0.16	− 0.09	− 0.85^{c}	− 0.88^{c}	− 0.91^{c}	–				
< 1 mm	0.30^{c}	− 0.25^{c}	− 0.21^{b}	− 0.49^{c}	0.59^{c}	− 0.25^{b}	0.48^{c}	− 0.38^{c}	0.14	− 0.23^{b}	− 0.04	− 0.99^{c}	− 0.99^{c}	− 0.99^{c}	0.89^{c}	–			
OC	− 0.47^{c}	− 0.07	− 0.11	0.73^{c}	− 0.73^{c}	0.46^{c}	− 0.74^{c}	0.53^{c}	0.03	0.47^{c}	− 0.07	0.71^{c}	0.71^{c}	0.69^{c}	− 0.60^{c}	− 0.71^{c}	–		
OC	− 0.47^{c}	− 0.07	− 0.11	0.73^{c}	− 0.73^{c}	0.46^{c}	− 0.74^{c}	0.53^{c}	0.03	0.47^{c}	− 0.07	0.71^{c}	0.71^{c}	0.69^{c}	− 0.60^{c}	− 0.71^{c}	1.00^{c}	–	
CS	− 0.40^{c}	− 0.00	− 0.04	0.37^{c}	− 0.36^{c}	− 0.12	− 0.11	0.26^{c}	− 0.14	− 0.30	0.12	0.18	0.16	0.11	0.04	− 0.15	0.39^{c}	0.39^{c}	–

[a] *cs* coarse sand, *fs* fine sand, *sm* soil moisture, *sd* soil density, *map* macroporosity, *mip* microporosity, *tp* total porosity, *srp* soil resistance to penetration, *gmd* geometric mean diameter, *wad* weighted averagediameter, *oc* organic carbon, *oc* organic matter, *cs* carbon stock

[b] Significant at the 5% probability

[c] Significant at 1% probability

of Archaeological Black Earth (ABE) in the southern region of Amazonas.

The SD had negative correlation ($p < 0.01$) with MAP (− 0.75), TP (− 0.76), OC (− 0.74), SM (− 0.68) and silt (− 0.63), and positive ($p < 0.01$) correlation with clay (0.58) and ($p < 0.05$) with sand (0.23). This can be related to the different types of soils and uses of the environments, since the soils with greater clay content can be more easily altered, with influences of the handling practices (traffic of machines and animals) that can compact the soil, by the reduction of porous spaces and consequent increase in SD. Normally, SD correlates better with sand, as occurred in the work of Cunha et al. (2017), where SD had a better positive correlation with sand (0.48) and then with clay (0.17), an inverse effect to what occurred in the present work. This can be justified by filling the spaces between the sand particles by the clay, making the soil more susceptible to compaction.

Soil moisture had a higher positive correlation ($p < 0.01$) with TP (0.86), MIP (0.68), OC (0.46) and MAP (0.31), corroborating with the results of Cunha et al. (2017) and Bergamin et al. (2015) with MIP. The SM also had a higher negative correlation ($p < 0.01$) with SD (− 0.68) and with SPR (− 0.52), which were similar to the results obtained both by Cunha et al. (2017) and by Bergamin et al. (2015). However, SPR tends to decrease in moist soils, favouring the correlation obtained in this research. According to Silveira et al. (2010), soils with low water content, present particles closer and difficult to be separated, with the increase of SPR, being evident the power of lubrication of water in the soil. These results only confirm that, during the compaction, the porous spaces decrease and increase in SD and SPR and decrease in SM. This can be observed in Table 7, where MAP had a positive ($P < 0.01$) correlation with TP (0.63), OC (0.53) and silt (0.48) and correlation ($p < 0.01$) negative with SD (− 0.75), SRP (− 0.43) and clay (− 0.48).

Concerning soil texture, a negative correlation ($p < 0.01$) between clay and silt (− 0.95) and a positive correlation ($p < 0.01$) with OC (0.73) was observed. It can be attributed to the process of displacement of finer particles, both horizontally and vertically, influencing the distribution of soil particle size (texture), which was also verified in the work of Cunha et al. (2017).

Through the factorial analysis it was possible to verify that the results were significant (KMO = 0.74 and $p < 0.05$ for the Barlett sphericity test), indicating, therefore, that it was adequate for the evaluated attributes. For the principal component analysis (PCA), the number of factors to be extracted was established in such a way that they explained at least 70% of the total data variance (Table 8 and Fig. 2), which presented covariance matrix eigenvalues greater than one (1) (Manly 2008), with 6.47 at CP1 and 3.62 at CP2. From the percentage of variance explained, it was observed that CP1 is responsible for 46.18% of the total variance of 72.01%, while CP2 accounts for 25.83%, which was sufficient to explain the variability of the data originals, Since the components only work in two axes, in the two axes that present the largest variance, the remainder of the variation value is not significant for the analysis of principal components.

Table 8 Correlations between each main component and analyzed variables and factorial analysis of soil attributes referring to a depth of 0.00–0.20 m, with rotational factors (varimax) (Factor CP1 and CP2) corresponding to the environments studied in the southern region of Amazonas, Brazil

Attributes (1)	Common variance	Factors	
		CP1	CP2
Silt	0.56	0.72*	0.20
Clay	0.63	− 0.79*	− 0.09
SM	0.75	0.09	0.86*
SD	0.87	− 0.46	− 0.81*
MAP	0.59	0.35	0.69*
TP	0.91	0.12	0.94*
SPR	0.61	0.15	− 0.77*
GMD	0.85	0.91*	0.14
WAD	0.80	0.89*	0.13
> 2.00 mm	0.79	0.88*	0.13
2.00–1.00 mm	0.57	− 0.76*	− 0.02
< 1.00 mm	0.79	− 0.88*	− 0.13
OC	0.75	0.78*	0.37
Variance Explained (%)		46.18	25.83

SM—soil moisture, *SD* soil density, *MAP* macroporosity, *TP* total porosity, *SPR* soil penetration resistance, *GMD* geometric mean diameter, *WAD* weighted average diameter, *OC* organic carbon, *FD* fractal dimension

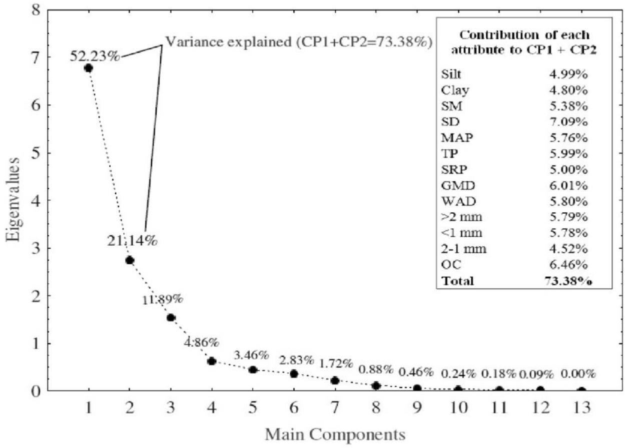

Fig 2. Proportion of variation in the data set explained by the main component (CP) and contribution of each variable to explain the total variance by the screeplot method. *SM* soil moisture, *SD* soil density, *MAP* macroporosity, *TP* total porosity, *SPR* soil penetration resistance, *GMD* geometric mean diameter, *WAD* weighted average diameter, *OC* organic carbon, *FD* fractal dimension

It was verified that Oliveira et al. (2013) and Cunha et al. (2017) found values of variance above 70% in soil physical and chemical attributes, and these values can be attributed to the variability of these attributes. Both factors (CP1 and CP2) presented high coefficients of determination for textural characteristics, structural stability of the aggregates and organic carbon of soil study (Table 8).

Figure 2, with "screeplot", graph, can also be used to verify the importance and contribution of each variable to explain the total variance. This graph together with the eigenvalues can be used to make the decision of how many components should be retained for later application of the principal component analysis (PCA). The weights of the attributes of each environment in the first and second retained components show that the most significant attributes for 72.01% of the variability explained in the 0.00–0.20 m depths were: silt (3.96%), clay (4.50%), SM (5.39%), SD (6.21%), MAP (4.22%), TP (6.48%), SPR (4.39%), GMD (6.10%), WAD (5.73%), > 2 mm (5.63%), 2–1 mm (4,09%), < 1 mm (5.62%) e OC (5.34%) (Fig. 2). Given that these attributes possibly have a greater impact or change, in relation to the other attributes.

Figure 3 shows the factorial plan of distribution of the scores of the different environments studied and the arrangement of the factorial loads of the soil attributes, collected at a depth of 0.00–0.20 m, formed by CP1 and CP2. 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).

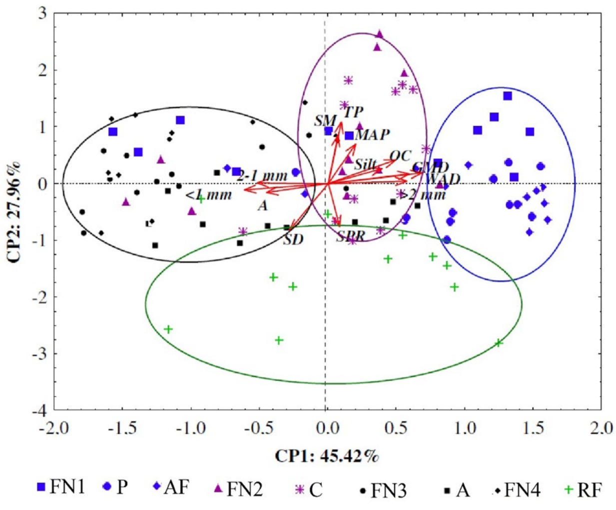

Fig 3. Factorial plan of soil attributes collected at a depth of 0.00-0.20 m in soils under natural environments and in anthropic uses in the southern region of Amazonas, Brazil. Values are standardized so that the mean is zero and the distances between the scores are measured by the standard deviation. *NF1* native forest 1, *P* pasture, *AF* agroforestry, *NF2* native forest 2, *C* cassava, *NF3* native forest 3, A-acai, *NF4* native forest 4, *RF* reforestation

It is observed a greater densification of the scores in the environments with NF1, P and AF distributed between the first and fourth quadrants, which discriminates these three environments in a significantly homogeneous group. Thus, soil samples collected in the environments under NF1, P and AF resulted in values for OC, silt, GMD, WAD and aggregate classes > 2 mm above the mean, in comparison to the other environments, positively correlated with to CP1, clay, aggregate classes 2–1 mm and < 1 mm below average, compared to the other environments, negatively correlated with CP1. On the other hand, the soil samples collected in the environments under NF3, A and NF4 are more distributed between the second and third quadrants, with attributes clay, classes of aggregates 2–1 mm and < 1 mm above the mean, compared to other environments, negatively correlated with CP1, and OC, silt, GMD, WAD, and aggregate classes > 2 mm below the mean and positively correlated with CP1.

The soil samples collected in the environments under NF2 and C were more distributed in the first quadrant and resulted in values for the attributes SM, TP and MAP above the average, in comparison to the other environments, positively correlated with CP2, and SD and SPR attributes below the mean, compared to other environments, negatively correlated with CP2. On the other hand, the soil samples collected in RF environments are more distributed between the third and fourth quadrants, with SD and SPR above average, compared to the other environments, negatively correlated with CP2, and the SM attributes, TP and MAP below the mean and positively correlated with CP2.

With this perspective, the characterization of the environments with NF2, C and RF were summarized in terms of the structural characteristics (SM, MAP, TP, SD and SRP), and the first two environments presented better values of SM, MAP and TP with low values of SD and SRP, whereas RF showed higher values in SD and SRP with lower values in SM, MAP and TP, which, in this case, may be associated to a higher level of compaction and resistance to soil rupture (Soares et al. 2015). In the environments with NF1, P, AF, NF3, NF4 and A, the characterization of these environments was summarized in terms of the texture, aggregate stability, organic carbon and soil texture, having higher values of OC, silt, GMD, WAD and aggregates > 2 mm the environments with NF1, P and AF, which presented lower values of clay and aggregates of smaller sizes (2–1 and < 1 mm), while NF3, NF4 and A presented the exact opposite.

It was possible to observe that the acai berry was in an area with greater similarity to all areas of the natural forest, configuring that few changes are being made due to the substitution of the natural environment. This fact is clearly associated with the fact that an acai is a palm tree native to the Amazon rainforest, that is, its ecosystem mechanism is the same as the general forest species of the region, and when and when a substituted being is displayed to the ground, it is suffering only since it is a cultivar with characteristics similar to the original vegetation (Yuyama et al. 2011).

It is also possible to verify that the data related to the soil aggregation correlate well with the pasture area, bringing good results, since this use is the most used machinery material for its implementation (Chioderoli et al., 2012), as well as As the attributes related to carbon and porous spaces were positively related to the cassava area, this can be justified by taking into account the rusticity of this cultivar, that is, it requires few cultural treatments related to soil preparation, thus freeing of factors. conditioning factors that affect porous spaces (Oliveira et al., 2013).

Conclusions

The different anthropic uses of the environments cause significant changes, both positive and negative, in the texture and structure of the soils when compared to their natural environments. The agroforestry environment presents the highest gains of organic carbon, organic matter and carbon stock up to 0.10 m depth and the environment with reforestation with the greatest loss up to 0.20 m depth, compared to its environments natural. The structural improvement of the analysed soils is closely related to the increase of organic carbon.

The environments with native forest 1, pasture and agroforestry are characterized by higher values of organic carbon, silt, geometric mean diameter, weighted average diameter and aggregates > 2 mm, while native forest 3, clay and aggregates between 2 and 1 mm and < 1 mm. The organic carbon has a positive correlation with silt, geometric mean diameter, weighted average diameter and aggregates > 2 mm, and negative with soil density and clay.

The environments with native forest 2 and with cassava are characterized by the highest values of soil gravimetric moisture, macroporosity and total porosity, while the environment with reforestation by the highest values of soil density and soil resistance to penetration.

What defines the degree of soil degradation that a particular crop can cause is the way it is planted, that is, when done incorrectly even a simple crop can cause serious damage to the soil, as well as others, crops that are totally different from the natural forest but properly implemented, can be the least harmful, such as pasture at work that most closely resembled its forest environment.

Aknowledgments The authors thank CNPq, FAPEAM and DINTER/CAPES for research funding.

References

Alvarenga RC, Fernandes B, Silva TCA, Resende M (1986) Estabilidade de agregados de um latossolo roxo sob diferentes métodos de preparo do solo e de manejo da palha do milho. Revista Brasileira de Ciência do Solo Viçosa 10:273–277

Araújo EA, Ker JC, Mendonça ES, Silva IR, Oliveira EK (2011) Impacto da conversão floresta—pastagem nos estoques e na dinâmica do carbono e substâncias húmicas do solo no bioma amazônico. Acta amazônica 41:103–114

Arraes RDA, Mariano FZ, Simonassi AG (2012) Causas do desmatamento no Brasil e seu ordenamento no contexto mundial. Revista Econ Sociol Rural 50:119–140

Baver LD, Gardner WH, Gardner WR (1972) Soil physics, 4th edn. Wiley, New York, p 529p

Bergamin AC, Vitorino ACT, Franchini JC, Souza CMA, Souza FR (2010) Compactação em um latossolo vermelho distroférrico e suas relações com o crescimento radicular do milho. Revista Brasileira de Ciência do Solo (Impresso) 34:681–691

Bergamin AC, Vitorino ACT, Souza FR, Venturoso LR, Bergamin LPP, Campos MCC (2015) Relationship of soil physical quality parameters and maize yield in a Brazilian Oxisol. Chilean J Agric Res Chillán 75:357–365

BRASIL (1978) Ministério das Minas e Energia. Projeto RADAM-BRASIL, folha SB. 20, Purus. Rio de Janeiro. 561p.

Bronick CJ, Lal R (2005) Soil structure and management: a review. Geoderma 124:3–22

Burak DL, Passos RR, Sarnaglia SA (2010) Utilização da análise muitivariada na avaliação de parâmtros geomorfológicos e atributos físicos do solo. Enciclopédia Biosfera 6:1–11

Campos MCC, Marques Júnior J, Souza ZM, Siqueira DS, Pereira GT (2012a) Discriminationofgeomorphicsurfaceswithmultivariateanalysisofsoilattributes in sandstone—basaltlithosequence. Revista Ciência Agronômica (UFC Online) 43:429–438

Campos MCC, Ribeiro MR, Souza Júnior VS, Ribeiro Filho MR, Almeida MBC (2012b) Topossequência de solos na transição campos naturais-floresta na região de Humaitá, Amazonas. Acta Amazônica (Impresso) 42:387–398

Campos MCC, Ribeiro MR, Souza Junior VS, Ribeiro Filho MR, Aquino RE, Oliveira IA (2013) Superfícies geomórficas e atributos do solo em uma topossequência de transição várzea-terra firme. Bioscence J Uberlândia 29:132–142

Castro Filho C, Muzilli O, Podanoschi AL (1998) Estabilidade dos agregados e sua relação com o teor de carbono orgânico em um latossolo roxo distrófico, em função de sistemas de plantio, rotações de culturas e métodos de preparo das amostras. Revista Brasileira de Ciência do Solo 22:527–538

Chioderoli CA, Mello LM, Grigolli PJ, Furlani CE, Silva JO, Cesarin AL (2012) Atributos físicos do solo e produtividade de soja em sistema de consórcio milho e braquiária. Revis Bras Engenharia Agrícola Ambiental 16:37–43

Collares GL, Reinert DJ, Reichert JM, Kaiser DR (2006) Qualidade física do solo na produtividade da cultura do feijoeiro num Argissolo. Pesquisa Agropecuária Brasileira 41:1663–1674

Cruz CD, Regazzi AJ (2001) Modelos biométricos aplicados ao melhoramento genético, 2ed. Viçosa, UFV, p 390

Cunha JM, Gaio DC, Campos MCC, Soares MDR, Silva DMP, Lima AFL (2017) Atributos físicos e estoque de carbono do solo em áreas de Terra Preta Arqueológica da Amazônia. Revista Ambiente e Água Taubaté 12:263–281

Cunha EQ, Stone LF, Moreira JAA, Ferreira EPB, Didonet AD, Leandro WM (2011) Sistemas de preparo do solo e cultura de cobertura na produção orgânica de feijão e milho. Revis Brasileira Ciência Solo 35:589–602

Desjardins T, Barros E, Sarrazin M, Girardin C, Mariotti A (2004) Effects of forest conversion to pasture on soil carbon content and dynamics in Brazilian Amazonia. Agr Ecosyst Environ 103:365–373

Domingues MSD, Bermann C, Manfredini S (2017) A produção de soja no Brasil e sua relação com o desmatamento na Amazônia. Revis Presença Geogr 1:32–47

Dutra S, Mascarenhas REB, Teixeira LB (2000) Controle de plantas invasoras em pastagens cultivadas. Pastagens cultivadas na Amazônia. Belém, Embrapa Amazônia Oriental, pp 72–98

EMBRAPA (2011) Manual de métodos de análise de solo. Centro Nacional de Pesquisa de Solos, Rio de Janeiro, p 230

EMBRAPA (2013) Sistema Brasileiro de Classificação de Solos. Centro Nacional de Pesquisa de Solos. 3.ed. revisada e ampliada. Brasília. 353p.

Feng G, Wu L, Letey J (2002) Evaluating aeration criteria by simultaneous measurement of oxygen diffusion rate and soil-water regime. Soil Sci 197:495–503

Ferreira MM (2010) Caracterização Física do Solo; Física do Solo. Editor Quirijn de Jong van Lier, Viçosa: Sociedade Brasileira de Ciência do Solo 298 p.

Freitas L, Casagrande JC, Desuó IC (2011) Atributos químicos e físicos de solo cultivado com cana-de-açúcar próximo a fragmento florestal nativo. Holos Environ Rio Claro 11:137–147

Giarola NFB, Tormena CA, Dutra AC (2007) Physical degradation of a red latosol used for intensive forage production. Revis Brasileira Ciência Solo 31:863–873

Goulart RZ, Lovato T, Pizzani R, Ludwig RL, Schaefer PE (2010) Comportamento de atributos físicos do solo em sistema de integração lavoura-pecuária. Enciclopédia Biosfera Goiânia 6:1–15

Jakob AAE. Estudo da correlação entre mapas de variabilidade de propriedades do solo e mapas de produtividade para fins de agricultura de precisão (1999) 145 f. Dissertação (Mestrado)—Faculdade de Engenharia agrícola—FEAGRI, Campinas.

Kemper WD, Chepil WS (1965) Size distribution of aggregates. In: Black CA, Evans DD, White JL, Ensminger LE, Clark FE (ed). Methods of soil analysis-Physical and mineralogical properties, including statistics of measurement and sampling. Agronomy Series 9. American SocietyofAgronomy, Madison. 499–510.

Lima CGR, Carvalho MP, Mello LMM, Lima RC (2007) Correlação linear e espacial entre a produtividade de forragem, porosidade total e a densidade do solo de Pereira Barreto (SP). Revis Brasileira Ciência Solo Viçosa 31:1233–1244

Liu XB, Zhang XY, Wang YX, Sui YY, Zhang SL, Herbert SJ, Ding G (2010) Soil degradation: a problem threatening the sustainable development of agriculture in Northeast China. Plant Soil Environ 56:87–97

Maia MAM, Marmos JL (2010) Geodiversidade do estado do Amazonas. CPRM, Manaus, pp 73–77

Manly BJF (2008) Métodos estatísticos multivariados: uma introdução, 3rdª edn. Bookman, Porto Alegre

Marchão RL, Vilela L, Paludo AL, Júnior RG (2009) Impacto do pisoteio animal na compactação do solo sob integração lavoura-pecuária no Oeste Baiano. EMBRAPA, Planaltina, DF, p 6p

Marques Júnior J. Caracterização de áreas de manejo específico no contexto das relações solo-relevo (2009) 113 f. Tese (Livre-Docência) - Faculdade de Ciências Agrárias e Veterinárias, Universidade Estadual Paulista, Jaboticabal.

Martins GC, Ferreira MM, Curi M, Vitorino ACT, Silva MLN (2006) Campos nativos e matas adjacentes da região de Humaitá (AM): atributos diferenciais dos solos. Ciência Agrotecnol 30:221–227

Melo VF, Orrutéa AG, Motta ACV, Testoni SA (2017) Land use and changes in soil morphology and physical-chemical properties in Southern Amazon. Revis Brasileira Ciência do Solo 41:1–14

Morais TPS, Pissarra TCT, Reis FC (2012) Atributos físicos e matéria orgânica de um Argissolo Vermelho-Amarelo em microbacia hidrográfica sob vegetação nativa, pastagem e cana-de-açúcar. Enciclopédia Biosfera Goiânia 8:213–223

Moreira A, Malavolta E (2004) Dinâmica da matéria orgânica e da biomassa microbiana em solo submetido a diferentes sistemas de manejo na Amazônia Ocidental. Pesquisa Agropecuária Brasileira 39:1103–1110

Oliveira JOAP, Vidigal Filho PS, Tormena CA, Pequeno MG, Scapim CA, Muniz AS, Sagrilo E (2001) Influência de sistemas de preparo do solo na produtividade da mandioca (Manihot esculenta, Crantz). Revista Brasileira Ciência Solo 25:443–450

Oliveira IA, Campos MCC, Soares MDR, Aquino RE, Marques Junior J, Nascimento EP (2013) Variabilidade espacial de atributos físicos em um cambissolo háplico sob diferentes usos na região sul do Amazonas. Revis Brasileira Ciência Solo Viçosa 37:1103–1112

Pagliai M, Marsili A, Servadio P, Vignozzi N, Pellegrini S (2003) Changes in some physical properties of a clay soil in Central Italy following the passage of rubber tracked and wheeled tractors of medium power. Soil Till Res 73:119–129

Paul BK, Vanlauwe B, Ayuke F, Gassner A, Hoogmoed M, Hurisso TT, Koala S, Lelei D, Ndabamenye T, Six J, Pulleman MM (2013) Medium-term impact of tillage and residue management on soil aggregate stability, soil carbon and crop productivity. Agr Ecosyst Environ 164:14–22

Portugal AF, Costa ODV, Costa LM (2010) Propriedades físicas e químicas do solo em áreas com sistemas produtivos e mata na região da Zona da Mata mineira. Revis Brasileira Ciência Solo Viçosa 34:575–585

Pragana RB, Ribeiro MR, Nóbrega JCA, Ribeiro Filho MR, Costa JA (2012) Qualidade física de Latossolos Amarelos sob plantio direto na região do Cerrado piauiense. Revis Brasileira Ciência Solo 36:1591–1600

Reinert DJ, Reichert JM (2006) Propriedades Físicas do Solo, Universidade Federal de Santa Maria, Centro de Ciências Rurais, pp 18

Rivero S, Almeida O, Ávila S, Oliveira W (2009) Pecuária e desmatamento: uma análise das principais causas diretas do desmatamento na Amazônia. Nova Economia Belo Horizonte 19:41–66

Rosolen V, Herpin U (2008) Expansão dos solos hidromórficos e mudanças na paisagem: um estudo de caso na região sudeste da Amazônia Brasileira. Acta Amazonica 38:483–490

Sá IB, Cunha TJF, Teixeira AHC, Angelotti F, Drumond FM (2010) Desertificação no Semiárido brasileiro. ICID+18 2a Conferência Internacional: Clima, Sustentabilidade e Desenvolvimento em Regiões Semiáridas, Fortaleza.

Salimon CI, Wadt PGS, Melo AWF (2007) Dinâmica do carbono na conversão de florestas para pastagens em Argissolos da Formação Geológica Solimões, no Sudoeste da Amazônia. Revis Biol Ciências Terra 7:29–38

Salton JC, Fabricio AC, Machado LAZ, Oliveira H (2002) Pastoreio de aveia e compactação do solo. Revis Plantio Direto Passo Fundo 69:32–34

Santos LAC, Campos MCC, Costa HS, Pereira AR (2012) Caracterização de solos em uma topossequência sob terraços aluviais na região do médio rio Madeira (AM). Ambiência 8:319–331

Silva AS, Lima JSS, Xavier AC, Teixeira MM (2010) Variabilidade espacial de atributos químicos de um Latossolo Vermelho-Amarelo húmico cultivado com café. Revis Brasileira Ciência Solo Viçosa 34:15–22

Silva CG, Alves Sobrinho T, Vitorino ACT, Carvalho DF (2005) Atributos físicos, químicos e erosão entressulcos sob chuva simulada, em sistemas de plantio direto e convencional. Engenharia Agrícola 25:144–153

Silva JAB, Fontana RLM, Costa SS, Rodrigues AJ (2015) Teorias demográficas e o crescimento populacional no mundo. Cad Graduação-Ciências Hum Sociais-UNIT 2:113–124

Silva JE, Resck DVS, Corazza EJ, Vivaldi L (2004) Carbon storage in clayey oxisol cultivated pastures in the "cerrado" region, Brazil. Agr Ecosyst Environ 103:357–363

Silveira DC, Filho JFM, Sacramento JAS, Silveira ECP (2010) Relação umidade versus resistência à penetração para um Argissolo Amarelo distrocoeso no recôncavo da bahia. Revis Brasileira Ciência Solo 34:1–67

Siqueira Neto M, Piccolo MC, Scopel E, Costa Junior C, Cerri CC, Bernoux M (2009) Carbono total e atributos químicos com diferentes usos do solo no cerrado. Acta Scientiarum Agronomy 31:709–717

Soares Filho R. Identificação e avaliação dos sistemas motomecanizados de preparo periódico do solo, usados no município de Rio Verde-GO. 1992. Viçosa: UFV, (1992) 64p. Dissertação (Mestrado em Engenharia Agrícola)—Universidade Federal de Viçosa, Viçosa.

Soares MDR, Campos MCC, Oliveira IA, Cunha JM, Santos LAC, Fonseca JS, Souza ZM (2016) Atributos físicos do solo em áreas sob diferentes sistemas de usos na região de Manicoré, AM. Revis Ciências Agrárias (Belém) 59:9–15

Soares MDR, Campos MCC, Souza ZM, Brito WBM, Franciscon U, Castioni GAF (2015) Variabilidade espacial dos atributos físicos do solo em área de Terra Preta Arqueológica sob pastagem em Manicoré. AM Revis Ciências Agrárias 58(4):434–441

Souza HA, Marcelo AV, Centurion JF (2012) Carbono orgânico e agregação de um Latossolo Vermelho com colheita mecanizada de cana-de-açúcar. Revis Ciência Agron 43:658–663

Statsoft INC. 2004. Statistica—data analysis software system. Tulsa.

Steinbeiss S, Gleixner G, Antonietti M (2009) Effect of biochar amendment on soil carbon balance and soil microbial activity. Soil Biol Biochem 41:1301–1310

Tavares Filho J, Tessier D (2009) Compressibility of oxisol aggregates under notill in response to soil water potential. Revis Bras Ciênc Solo 33:1525–1533

Vale Júnior JF, Souza MIL, Nascimento PPRR, Cruz DLS (2011) Solos da Amazônia: etnopedologia e desenvolvimento sustentável. Revis Agro@mbiente On-line 5: 158–165.

Yuyama LKO, Aguiar JPL, Silva Filho DF, Yuyama K, Varejão MDJ, Fávaro DIT, Caruso MSF (2011) Caracterização físico-química do suco de açaí de Euterpe precatoria Mart. oriundo de diferentes ecossistemas amazônicos. Acta Amazonica 41:545–552