v. 5, n. 5, 2025

Journal of Agricultural Sciences Research

Acceptance date: 21/05/2025

CHARACTERIZATION OF ARCHAEOLOGICAL BLACK EARTHS IN THE MUNICIPALITY OF GURUPÁ-PA

Adriano dos Santos Moura
PhD, Bradesco Foundation, Paragominas Pará-Pará, Brazil. Correspondence
https://orcid.org/0000-0003-0027-4530

Herdjania Veras de Lima
Institute of Agricultural Sciences, Federal Rural University of the Amazon, Belém-Pará, Brazil
https://orcid.org/0000-0002-2178-8250

Helena Pinto Lima
Coordination of Human Sciences, Museu Paraense Emílio Goeldi, Belém-Pará, Brazil
https://orcid.org/0000-0001-5787-7231

Katiane Raquel Mendes Barros
PhD Studant, Museu Paraense Emílio Goeldi, Belém-Pará, Brazil
https://orcid.org/0000-0002-8962-6549

Peola Reis de Souza
PhD student, Federal Rural University of the Amazon, Belém-Pará, Brazil
https://orcid.org/0000-0002-8102-0905

Abstract: Because of their anthropogenic origin, archaeological terra preta soils (TPA) provide information about the interactions between human populations and their environments over time. Studies aimed at clarifying these ancient settlements and the specific characteristics of the black earth soils associated with them have advanced in recent decades and have pointed to the internal variability of this type of soil. With this in mind, the aim of this study was to verify the soil attributes in areas of terra preta in different locations in the municipality of Gurupá-Pará, in order to contribute to an understanding of the formation of TPAs in this region. For this physical-chemical characterization of the soil, 8 points were collected in 8 locations with 3 depths: 10cm, 20cm and 30cm and 10 points were collected in the same locations. For aggregate stability, samples were taken at three depths. For chemical analysis, 10 soil samples were collected from each location. For mineralogical analysis, 3 TPA profiles were collected at the Gurupá-miri, Carrazedo and Gurupá sites. The DMP results show that the percentage distribution of aggregates (PDA) at a depth of 10cm was highest in the 4.76 mm class, remaining the same at the other two depths, except at site 4. Base saturation above 50% at all sites (L) attributes the Eutrophic character. Aluminum was very high and the nutrients Calcium (Ca), Phosphorus (P) and Magnesium (Mg) behaved in the same way. The predominance of kaolinite (Kt) in the three profiles analyzed was expected; goethite (gth), gibbsite (gb), strangite (str), albite (Ab), anatase (An) and tridymite (Tr) were also observed in terra preta soils, disappearing with increasing depth.

Keywords: Formation; aggregate stability; mineralogy

INTRODUCTION

The soils of archaeological sites in the Amazon, known as terra preta arqueológica (TPA), in particular, provide important information about past relationships between human populations and their environments. Research is currently focusing on the interpretation of human artifacts, organic materials buried under soils and sediments, which can help to understand the changes that occur in soils, such as increased fertility and organic matter (GHILARDI, 2021) . Some analyses have become effective in finding answers to interpretations of land use in settlements and villages and the specific characteristics of soils with APT, including phosphate analysis, X-ray fluorescence, spectroscopy) and recently also including analysis of soil pH, magnetic susceptibility, organic carbon and soil nitrogen. (NEJMAN et al., 2018, 2020; SALISBURY, 2020)

There is still a lot to study when it comes to the formation of TPA soils. Macedo (et al., 2017) , reports behavior related to soil texture with organic matter, which alters the classification of profiles, possibly due to the interrelation/fusion of organic matter with sand-sized particles (SILVA et al., 2021)which confer their distinctive colouration. Frequent occurrences of pre-Columbian artefacts at ADE sites led to their ubiquitous classification as Anthrosols (soils of anthropic origin , shows that the characterization of clay mineralogy using X-ray diffraction showed no differences in the type of dominant clays found in the TPA profiles and adjacent areas.

Silva et al., (2021), points out in their work that there is a need for a broader view of landscape evolution as a way of understanding the formation of TPA and redirecting applications for sustainable use and soil conservation, such as research related to biochar (soil conditioners). Also according to the authors, TPA should be investigated for a potential alluvial origin, based on physical properties and elemental sources, to improve basic knowledge of the transition from nomadic to sedentary populations in the Amazon and its influence on socio-ecological trajectories. In contrast, Lombardo et al. (2020) point out in their work that the formation of anthropogenic areas is not just an incidental effect of food waste disposal, but can also be seen as an active process of niche construction.

The Amazon region has a large geomorphological configuration, human activity, changes in vegetation cover and flooding, all of which may indicate an alluvial contribution of nutrients to the site in the past and contribute to TPA studies.

Kern et al. (2017) point to the enormous variability of TPA soils between sites and different regions, as well as within sites. Therefore, even with advances in data (chemical, physical and biological) in studies to explain the formation and behavior of archaeological site soils, there is a need for more analysis of soil properties in different regions of the Amazon, which will contribute to research, given that archaeological sites are in different environments, climate and activities. With this in mind, the aim is to verify soil attributes in terra preta areas in different locations, in order to understand the formation of TPA soils.

MATERIAL AND METHODS

LOCATION

The sampling area is located in the municipality of Gurupá, in the state of Pará, in the mesoregion of Marajó and the micro-region of Portel, on the banks of the Amazon River, on the island of Marajó. It has high archaeological potential, with the presence of pre-colonial and colonial sites with TPA (LIMA et al., 2020). Gurupá was an old colonial nucleus of settlements that were established and developed from river navigation, floodplain agriculture on the river plains and the occupation of higher ravines on terraces and trays, where urban sites were established. Geographically, it lies between 03º14’22” and 03º15’47” South latitude and between 60º 13’02” and 60º 13’50” West latitude (Figure 1).

Sampling was carried out at TPA sites within the city of Gurupá (points called Gurupá-Airport and Gurupá-Church) and also at sites located in quilombola communities in the municipality, at the confluence of the Xingu and Amazonas rivers. These are Carrazedo, Gurupá-miri and Maria Ribeira. Within each area or site, locations with different land use and vegetation were selected, as shown in Table 1:

SAMPLING

Before selecting the collection areas, the soil was probed to verify the black earth TP points. Soil samples were then collected at 8 points in 8 locations in the municipality of Gurupá. At each point, deformed soil samples were collected at three depths: 10, 20 and 30 cm for stability analysis, for chemistry, 10 deformed samples were collected at each location at a depth of 20 cm, and for mineralogy, deformed samples were collected from three profiles at a depth of 10 cm.

SOIL AGGREGATE STABILITY

Undeformed soil samples were collected in blocks, 50g of soil were removed and 4.76 mm mesh diameters were passed through. The distribution of aggregates by average diameter class (2.0 ≥ X > 1.0 cm, 1.0 ≥ X > 0.5 cm, 0.5 ≥ X > 0.25 cm and 0.25 ≥ X > 0.105 cm) was obtained by subjecting the soil samples to wet sieving (Embrapa, 2017). To do this, 50 g samples were weighed, retained on the 4 mm sieve, moistened with a spray bottle, placed on a set of sieves with meshes of 2.00; 1.00; 0.500; 0.250, 0.105 and 0.053 mm, and subjected to vertical agitation in the Yooder apparatus for 15 minutes. After the specified

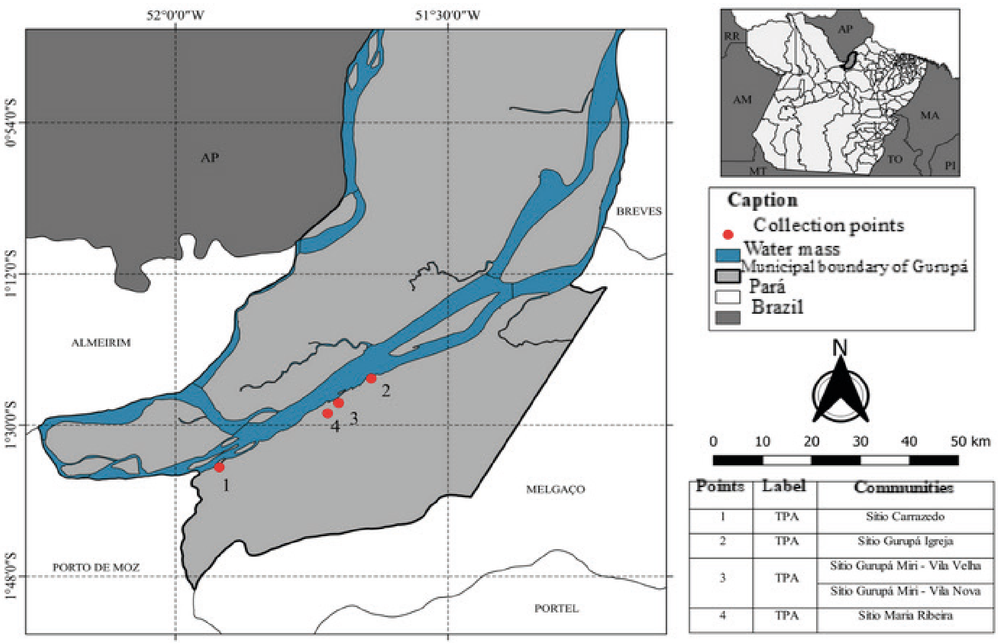

Figure 1: Map of the collection locations.

Geographic Coordinate System; Datum: SIRGAS 2000, Database: IBGE,2017

Subtitles	Location	Archaeological site	Type	Vegetation
L1	Gurupá	Carrazedo	TPA	Secondary forest
L2	Gurupá	Carrazedo	ADJ	Secondary forest
L3	Gurupá	Gurupá - Airport	ADJ	Creeping plants
L4	Gurupá	Gurupá - Church	TPA	Fruit trees
L5	Gurupá	Gurupá miri - vila Velha	TPA	Bare soil
L6	Gurupá	Gurupá miri - Vila Nova	TPA	Growing pupunha
L7	Gurupá	Maria Ribeira	TPA	Creeping plants
L8	Gurupá	Maria Ribeira	ADJ	Secondary forest

Table1 : Collection points in the municipality of Gurupá, State of Pará.

Adj: Adjacent; TPA: Terra Preta Arqueológica

time, the material retained on each sieve was removed separately using a water jet, placed on previously weighed and identified plates and taken to the oven (65 °C) until constant weight. After drying, the mass of aggregates retained on each sieve was obtained. The weighted average diameter (WAD) was calculated from the aggregate mass data. The WAD was calculated according to the following expression: WAD = ∑ xiyi ; where: X=1 i = class interval: 8.0mm ≥ X > 2.0 mm, from 2.0 ≥ X > 1.0 mm, from 1.0 ≥ X > 0.5 mm, from 0.5 ≥ X > 0.25 mm and from 0.25 ≥ X > 0.105 mm; xi = is the diameter of the class center (mm); yi = is the ratio between the mass of aggregates within the class (xi) and the total mass of aggregates (SALTON et al., 2017) .

SOIL DENSITY

The density of the soil (Ds) was obtained using the volumetric ring method, following the methodology proposed by methodology proposed by (ALMEIDA, BRIVALDO GOMES DE et al., 2017) .

CHEMICAL ANALYSIS

With regard to the chemical analyses: the soil pH was determined potentiometrically using a soil:water ratio of 1:2.5, in water and KCl; calcium, magnesium and exchangeable aluminum were extracted with a 1 mol L^{-1}K-Cl extractant solution and determined by atomic absorption spectrophotometry; potassium, sodium and available phosphorus were extracted using the $Mehlich^{-1}$extractant, with K^+ and Na^+ being determined by flame spectrophotometry, and P being determined by colorimetry. Potential acidity (H+Al) was extracted with 0.5 mol L^{-1}calcium acetate buffered solution at pH 7.0 and determined volumetrically with 0.025 mol L^{-1}NaOH solution (DONAGEMMA et al., 2017) . Based on the results of the chemical analyses, the sums of bases (S), cation exchange capacity (T), base saturation (V%) and percentage of aluminum saturation (m%) were calculated.

TOTAL ORGANIC CARBON AND CARBON STOCK

Total organic carbon was estimated by the loss on ignition at 450°C, while for inorganic carbon the loss on ignition temperature was 950°C (HOUBA et al., 1995). The samples were taken to the oven-drying condition by pre-treatment at 105°C. The difference between the weights at 450°C and 105°C gave the loss of organic matter content. Soil inorganic carbon was obtained by observing the mass loss between 450°C and 950°C and multiplying it by a conversion constant of 0.273 to convert the mass of CO2 into the mass of carbon. Soil carbon stocks were calculated according to equation 1:

$$C\ stoks\ (Mg\ ha^{-1}) = \sum_{i=1}^{j} Ci\ x\ Pi\ x\ di\ x\ 10000 \qquad \text{Eq. 1}$$

Where; Ci is the soil carbon (g $g^{-1)}$; ρi is the soil density (g $cm^{-3)}$, di is the depth of the soil layer (m) for layer i while j is the number of layers. The value of 10,000 indicates the stock for 1 ha of land.

MINERALOGICAL ANALYSIS

Mineralogical analysis was carried out on the clay fraction using X-ray diffraction (XRD). Three profiles were used in this analysis, Profile 1: (0-100cm); Profile 2: (0-240 cm) and Profile 3: (0-100 cm), to obtain the clay fraction and then carry out the mineralogical analysis.

To obtain the clay fraction, the samples from each horizon were dispersed with NaOH 0.1 mol $L^{(-1)}$ (chemical dispersant) and subjected to slow stirring in Wagner-type equipment for 16 hours (physical dispersion), as recommended by Gee and Or (2002).

The clay fraction was separated from the silt fraction by sinfonation into 10-liter plastic buckets at varying time intervals, always obeying Stockes' law to establish the collection height. After separation, the samples were dried in an oven at 60°C and then macerated in an agate mortar and passed through a 48 mesh sieve to homogenize the particles.

The analyses were carried out using an X-ray diffractometer (XRD) model Shimadzu XRD 6000. The samples were initially analyzed in XRD in the form of non-oriented powder, for a global assessment of the mineralogical assembly (JACKSON, 1975). The samples diffracted as unoriented powder were scanned from 3 to 50 ° 2ϴ at a speed of 1° 2 ϴ min^{-1}.

STATISTICS

Analyses of variance were carried out using the F test ($p < 0.05$), and the means were compared using the Tukey 5% test. The analyses were carried out using the R 3.5.1 program (R Development Core Team, 2017)

Size	Location							
	L1	L2	L3	L4	L5	L6	L7	L8
mm	--%--							
				0-10 cm				
4.760	93.66a	88.82a	79.92a	9.63d	88.67a	69.13a	86.30a	82.95a
2.000	2,41b	2.01b	3.27c	3.82e	1.98b	11.95b	2.34b	2.86bc
1.000	1.22b	1.95b	2.56c	7.55de	2.61b	6.97c	3.13b	4.34bc
0.500	0.89b	1.84b	11.70b	16.15c	2.98b	5.99cd	3.52b	4.46b
0.250	0.78b	1.81b	1.81c	30.79a	2.04b	3.97cd	3.26b	3.68bc
0.105	0.70b	1.32b	0.48c	22.30b	1.12b	1.76d	0.77b	1.11c
0.053	0.65b	2.26b	0.26c	10.76d	0.59b	1.22d	0.68b	0.59c
				10-20cm				
4.760	89.62a	87.50a	81.10a	32.27a	79.12a	88.24a	85.18a	93.35a
2.000	3.08b	4.00b	3.24b	1.95e	1.17b	1.95b	5.09b	0.62b
1.000	2.39bc	2.04bc	4.08b	4.82de	3.73b	2.67b	3.30b	1.23b
0.500	2.22bc	2.14bc	4.65b	8.89d	5.03b	2.13b	2.82b	1.83b
0.250	1.71bc	2.02bc	4.86b	20.78b	5.55b	1.15b	2.29b	2.19b
0.105	0.63c	0.50bc	1.04b	14.97c	2.07b	2.57b	0.50b	0.36b
0.053	0.46c	1.79c	1.03b	16.32c	3.33b	0.89b	0.81b	0.43b
				20-30 cm				
4.760	85.70a	5.83a	69.14a	9.90c	43.59a	31.10a	92.62a	79.21a
2.000	3.36b	0.42b	7.64b	2.30d	4.80d	3.26d	1.02b	2.39cd
1.000	2.72b	76.39bc	6.88b	5.66cd	10.09bc	11.77c	2.06b	3.92cd
0.500	2.64b	4.86bc	7.08bc	16.17b	13.58b	21.16b	1.59b	6.32b
0.250	2.42b	7.58cd	6.45bcd	24.97b	14.05b	20.91b	1.49b	4.40c
0.105	1.74b	2.01d	1.53cd	22.68a	5.25d	4.97cd	0.53b	1.35d
0.053	1.38b	2.90d	1.29d	18.32a	7.64cd	6.82cd	0.70b	2.40cd

Table2: Aggregate stability data from 8 collection sites in the municipality of Gurupá-Pa

Average values from three repetitions. Equal letters in the line indicate that the means do not differ at the 5% level. L1: Carrazedo TPA; L2: Carrazedo Adjacent soil; L3: Aeroporto Adjacent soil; L4: Gurupá igreja TPA; L5: Gurupá vila velha TPA; L6: Gurupá vila nova TPA; L7: Maria Ribeira TPA; L8: Maria Ribeira Adjacent soil.

RESULTS

DISTRIBUTION OF AGGREGATES

The percentage distribution of aggregates (PDA) at a depth of 10 cm was highest in the 4.76 mm class, reaching more than 50% in all locations except L4, which had the lowest PDA values. On the other hand, the highest proportion for this location was 30.79% and occurred in the 0.250 mm class (Table 2).

At a depth of 20 cm, L4 maintained its result, with the other sites having more than 50% of their aggregates in the 4.76mm class. At a depth of 30 cm, only in L1, L3, L7 and L8 was the PDA greater than 50%. The high PDA in the 4.76 class is possibly due to the high organic carbon content and consequently the carbon stock.

A case in point was locality 2, which is adjacent to the black earth soil. At a depth of 30 cm, the aggregates in the largest mesh decreased, due to the absence of binding factors that support aggregation. This was different in locality 4, an area of black earth soils, but the aggregates fell apart in the largest meshes.

Another issue is due to some factors that interfere with aggregation, such as: clay type and content, calcium carbonate, iron, aluminum and manganese oxides, organic plant exudates, organic substances from the action of microorganisms and other organic compounds. The wetting and drying cycles can also be included as an important environmental factor that interferes with soil aggregation.

Corroborating the results of the relative distribution of aggregates, the locations related to their depths showed a greater weighted average diameter (WAD), which did not differ from each other. The depths of 30 cm in L1, L2, L5 and L8 stand out.

The weighted average diameter (WAD) showed a significant difference ($p < 0.05$) between the depths and locations of the terra preta soils (Figure 2). When comparing depths, the Carrazedo site showed no significant difference at the 10 and 20 cm depths; this difference was observed at the 30 cm depth, reaching 3.45 mm WAD. This was not the case at the other sites considered to be black earth soils, where all the depths showed no significant difference.

The two adjacent soils behaved in the same way, showing a difference at a depth of 30 cm.

The highest value of 91.78 g kg^{-1}soil organic carbon (COS) was found in the L1 TPA area, which corresponds to the Carrazedo community that is configured as pre-colonial and historical. The dark color of the soil characterizes an area where there are fragments of ceramics and organic residues, which shows that the interaction between Europeans, Amerindians and Brazilians began in the 16th century. Sites L2, L3 and L8 are areas of adjacent soils and there was no statistical difference between them; however, there was a difference between the sites considered as TPA. The low organic carbon content is in line with the CO content in native forest areas. Sites L4, L5, L6 and L7 are TPA areas with high CO levels, as is L1. These are pre-colonial areas with a history of deposits of ceramic fragments, pottery and bones. These locations have high levels of organic carbon. Figure (2) shows this concentration in the stock of organic carbon in the soil at L1, L4, L5, L6 and L7, which is statistically different from locations L2, L3 and L8, which are considered adjacent soils.

High pH values were observed in L4 and L5 (6.31 and 6.83) respectively and low values of 3.69 and 3.88 for L7 and L8. The cation exchange capacity was high in L2, L5 and L6. Base saturation above 50 % at all sites (L) gives the soil its eutrophic character. Aluminum was very high at 3.23 in L8. On the other hand, the nutrients Calcium (Ca) and Phosphorus (P) and Magnesium (Mg) showed very high values of 11.90 and 6.96 cmol.$dm^{(-3}$) for L1 and L5 and 2796.44 and 3439.33 mg.$kg^{-1}$for L1 and L4 and 2.13 and 3.20 cmol.$dm^{(-)\,(3)}$. However, the other variables showed good content in the black earth and adjacent soils (Table 3).

MINERALOGICAL ATTRIBUTES OF THE CLAY FRACTION

X-ray diffraction (XRD) analyses were carried out on the clay fraction in three terra preta soil profiles and the results are shown in (Figure 4): Gurupá-miri site; (Figure 5): Carrazedo site; (Figure 6): Gurupá-igreja site. It can be seen that the mineralogy of the TPA soils is quite similar at the greatest depths in the three profiles.

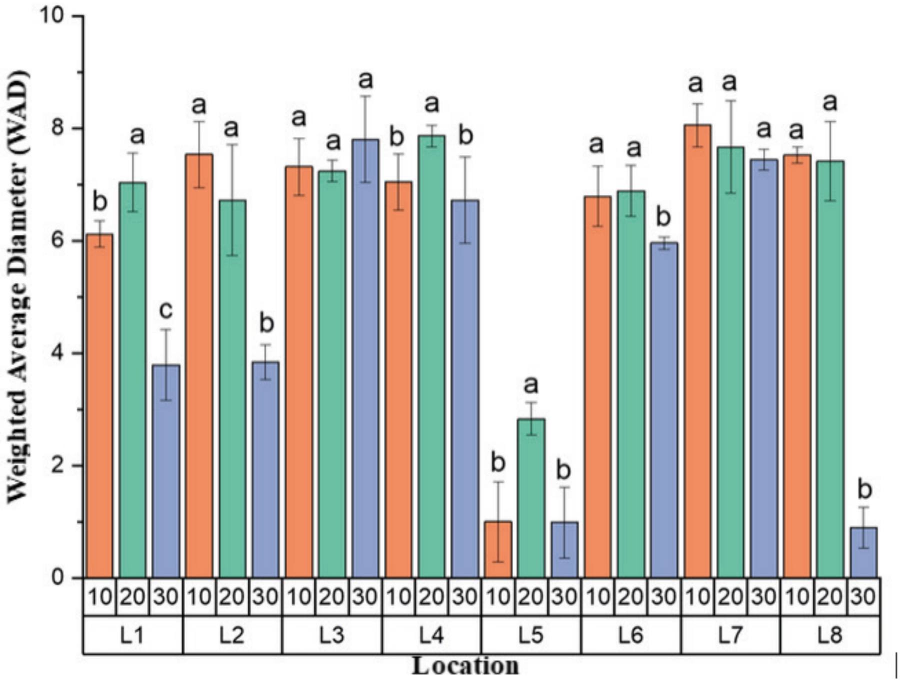

Figure 2: Average values from three repetitions. Equal letters in the line indicate that the means do not differ at the 5% level. L1: Carrazedo TPA; L2: Carrazedo Adjacent soil; L3: Aeroporto Adjacent soil; L4: Gurupá igreja TPA; L5: Gurupá vila velha TPA; L6: Gurupá vila nova TPA; L7: Maria Ribeira TPA; L8: Maria Ribeira Adjacent soil.

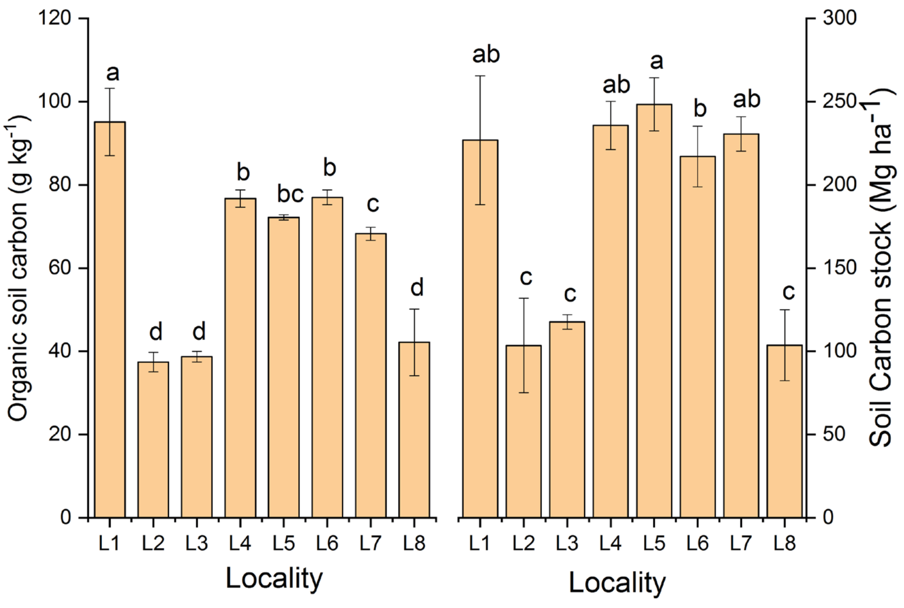

Figure 3: Average values from three repetitions. Equal letters in the line indicate that the means do not differ at the 5% level. L1: Carrazedo TPA; L2: Carrazedo Adjacent soil; L3: Aeroporto Adjacent soil; L4: Gurupá igreja TPA; L5: Gurupá vila velha TPA; L6: Gurupá vila nova TPA; L7: Maria Ribeira TPA; L8: Maria Ribeira Adjacent soil.

Loc	pH	Ca	Mg	Al	Al+H	K	P	SB	CTC pH 7 (T)	V	m
	1:2.5			cmol.dm^{-3}			mg.kg^{-1}			%	
L1	4.38d	11.90a	2.13b	0.30a	5.60e	5.22h	2796.44b	19.25f	24.85h	77.46d	1.53de
L2	4.43d	1.13e	1.80bc	2.20b	10.16b	73.58a	86.15e	76.51a	86.67a	88.28b	2.80d
L3	4.17e	0.76e	1.60bcd	2.20b	8.50c	21.21f	4.36e	23.57e	32.07f	73.50e	8.54a
L4	6.31b	5.10cd	1.23cd	1.16c	6.06d	16.21g	3439.33a	22.54e	28.60g	78.81d	4.89c
L5	6.83a	6.96b	1.23cd	0.76cd	4.10f	53.83b	2209.44c	62.02b	66.12b	93.80a	1.21e
L6	4.90c	3.83d	3.20a	0.46d	10.03b	46.27c	536.15d	53.30c	63.33c	84.16c	0.86e
L7	3.69g	5.16c	1.33bcd	0.53d	8.80c	36.26e	587.61d	42.75d	51.55e	82.93c	1.22e
L8	3.88f	0.93e	0.86d	3.23e	12.16a	41.38d	46.43e	43.17d	55.33d	78.02d	6.96b

Table3 : Data from the chemical analysis of archaeological black earth in the municipality of Gurupá-Pa

Average values from three repetitions. Equal letters in the line indicate that the means do not differ at the 5% level. L1: Carrazedo TPA; L2: Carrazedo Adjacent soil; L3: Aeroporto Adjacent soil; L4: Gurupá igreja TPA; L5: Gurupá vila velha TPA; L6: Gurupá vila nova TPA; L7: Maria Ribeira TPA; L8: Maria Ribeira Adjacent soil.

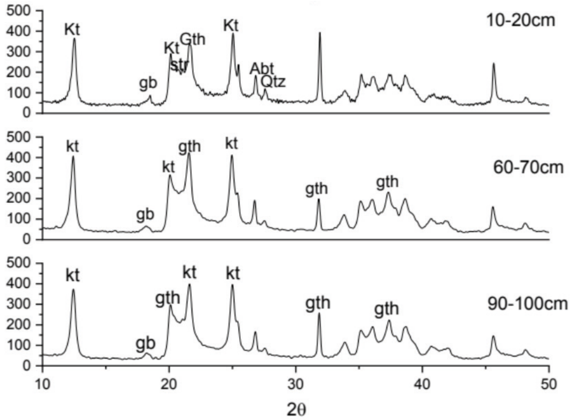

Figure 4: Mineralogy data from the profile at the Gurupá miri - vila Velha archaeological site

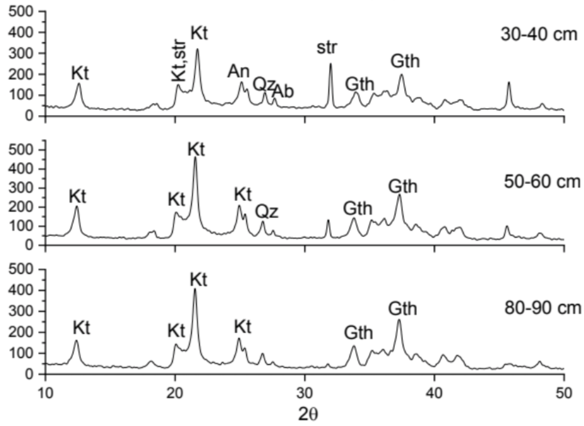

Figure 6: Mineralogy data from the profile at the Gurupá - Igreja archaeological site

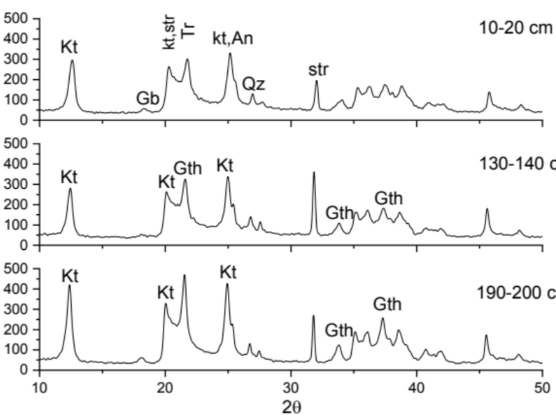

Figure 5: Mineralogy data from the profile at the Carrazedo archaeological site

The different minerals appeared at the initial depths in figure 4: at 20 cm; in figure 5: 20 cm and figure 6: 40 cm. With regard to the clay minerals, kaolinite (Kt) is the predominant mineral in all the profiles, with the presence of stringite (Str), albite (Ab), gbbsite (Gb), anatase (An), tridymite (Tr). In the three profiles from a depth of 60 cm, the predominant mineral is kaolinite and goethite.

DISCUSSION

DISTRIBUTION OF AGGREGATES AND THEIR RELATIONSHIP WITH ORGANIC CARBON

The largest aggregates were retained in the 4.76mm class in all locations, except for location 4 (table 1), where the amount of aggregate in the 0.250mm class can be seen, characterizing it as micro-aggregate, a behavior that is related to the amount of organic matter in the soil, corroborating with the organic carbon and carbon stock data (figure 3). This relationship was observed by (FROZZI et al., 2020)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 , clearly stating that there is a close relationship between organic carbon and DMP.

High levels of CO and the intense biological activity of microorganisms and roots, which promote the construction of channels and biopores, alter soil structure. In addition, soil aggregate stability is a well-recognized significant indicator of soil structure formation, degradation and stabilization (ABIVEN; MENASSERI; CHENU, 2009; ABRAR et al., 2020; MUSTAFA et al., 2020).previous research mostly explored the SOC in the topsoil and provided little or no information about its distribution in deeper layers and various protection mechanisms particularly under long-term fertilization. The present study investigated the contents and profile distribution (0–100 cm

Organic carbon is present in both locations (figure 3). One of the main peculiarities of terra preta soils in the Brazilian Amazon is the predominance of high levels of organic matter in the first centimeters of the topsoil. According to (KERN et al., 2019; KÖGEL-KNABNER; AMELUNG, 2021)Anthropic shell mounds (Sambaquis - terric Anthrosols , the amount of soil organic matter present in TPA is related to chemical recalcitrance, which contributes to the degree of condensation of organic carbon, consequently increasing the carbon stock as shown in (figure 3B). Also according to the author, the highest concentration of organic carbon is present superficially and decreases with depth at 20cm (ALBERTO QUESADA et al., 2020; MACHADO et al., 2017; SANTANA MACEDO et al., 2019) . This carbon stock generally increases with the number of carboxylic acids (MO quality), further increasing the degree of condensation (MO quantity) (GMACH et al., 2020; MAYER et al., 2019; MIKUTTA et al., 2006). by its inherent recalcitrance and by occlusion in aggregates. However, the relative contribution of these factors to OM stabilization is yet unknown. We analyzed pool size and isotopic composition (14C, 13C

According to Batistão et al., (2020), organic carbon is composed of organic and inorganic aromatic chains, bezenecarboxylic acids, resistant for a long period of time and which plays a major role in the formation of soil aggregate stabilization, improving the soil's physical and structural conditions (CAVASSANI et al., 2021) . dark-colored soils with increased fertility are identified and referred as Amazonian Dark Earths (ADE

RELATIONSHIP BETWEEN ORGANIC CARBON AND SOIL NUTRIENTS

Organic carbon contents in tropical anthropogenic soils are higher than in adjacent soils, and this phenomenon has also been found by (CORRÊA; SCHAEFER; GILKES, 2013; GLASER et al., 2000) , clearly referring to an enrichment in soil organic matter due to anthropogenic additions.

With the enrichment of TOC, anthropogenic soils have considerably higher amounts of P and Ca and Mg. This enrichment probably resulted from long-term anthropogenic activities and a low translocation of P in anthropogenic soils kern et al., 2019. This shows distinct evidence of previous anthropogenic activities, so P thresholds are needed as a diagnostic criterion or at least as an additional characteristic to classify and identify terra preta soils.

The elements P and Ca are limiting elements in tropical environments compared to black earth soils. According to Silva 2021, these excess elements could possibly explain the origin of TPA soils.

The cation exchange capacity (CEC) indicates a high capacity for cation sorption and nutrient storage (KERN et al., 2019; LIANG et al., 2006)especially for nutrient cycling. Anthrosols from the Brazilian Amazon (ages between 600 and 8700 yr BP . This is justified by the values found in (table 2).

MINERALOGY OF THE CLAY FRACTION

The predominance of kaolinite (Kt) in the three profiles analyzed was expected, since the soils are found in tropical Amazonian environments, whose environment favors the leaching of basic cations and silica, allowing the formation and stabilization of Kt in this environment, corroborating the results found by silva et al, 2011 in a chemical and mineralogical characterization of anthropogenic soils, and according to the author, goethite, gibbsite and anatase were also observed in terra preta soils. (NEGREIROS et al., 2020) , highlights in his work the presence of kaolinite and quartz, illite and anatase. (SANTOS et al., 2018)Araujo JKS, Souza Júnior VS, Campos MCC, Corrêa MM, Souza RAS. Pedogenesis in an Archaeological Dark Earth-Mulatto Earth catena over volcanic rocks in western Amazonia, Brazil. Rev Bras Cienc Solo. 2018;42:e0170359. ABSTRACT: Archaeological Dark Earth (ADE , shows in his work that kaolinite is the predominant mineral in the clay fraction for all the anthropogenic soils evaluated, and that the presence of this mineral is indicative of alteration.

The results found in this study were generally similar, with a predominance of minerals linked to black earth on the surface of the soil such as Strangite (str), Albite (Ab), anatase (An), tridymite (Tr), and not found at depth.

CONCLUSION

Aggregate stability is higher on the soil surface because it is strongly related to the soil's organic carbon content and stock, showing similar behavior between the sites, except at site L4.

The TPA soils are enriched in calcium and phosphorus and pH compared to adjacent soils, giving them a characteristic that can identify other archaeological terra preta sites, thus showing that anthropogenic influence alters the environment.

The mineralogy of the clay shows the minerals belonging to black earth soils concentrated in the first few centimetres of the soil surface and as the depth increases, the minerals kaolinite and goethite prevail.

REFERENCES

ABIVEN, S.; MENASSERI, S.; CHENU, C. The effects of organic inputs over time on soil aggregate stability - A literature analysis. **Soil Biology and Biochemistry**, v. 41, n. 1, p. 1–12, 2009.

ABRAR, M. M. et al. Variations in the profile distribution and protection mechanisms of organic carbon under long-term fertilization in a Chinese Mollisol. **Science of the Total Environment**, v. 723, p. 138181, 2020.

ALBERTO QUESADA, C. et al. Variations in soil chemical and physical properties explain basin-wide Amazon forest soil carbon concentrations. **SOIL**, v. 6, n. 1, 2020.

ALMEIDA, BRIVALDO GOMES DE et al. Densidade do solo. In: TEIXEIRA, P. C. et al. (Eds.). . **Manual de Métodos de Análise de Solo**. 3ª edição ed. Brasília, DF: [s.n.]. p. 65–75.

BATISTÃO, A. C. et al. Resilience and microstructural resistance of Archaeological Dark Earths with different soil organic carbon contents in Western Amazonia, Brazil. **Geoderma**, v. 363, n. July 2019, p. 114130, 2020.

CAVASSANI, R. DE S. et al. Amazonian dark earths in rondônia state: Soil properties, carbon dating and classification. **Revista Brasileira de Ciencia do Solo**, v. 45, 2021.

CORRÊA, G. R.; SCHAEFER, C. E.; GILKES, R. J. Phosphate location and reaction in an archaeoanthrosol on shell-mound in the Lakes Region, Rio de Janeiro State, Brazil. **Quaternary International**, v. 315, p. 16–23, 2013.

DONAGEMMA, G. K. et al. Análise granulométrica. In: **Manual de métodos de análise de solo**. [s.l: s.n.]. p. 437.

FROZZI, J. C. et al. Physical attributes and organic carbon in soils under natural and anthropogenic environments in the South Amazon region. **Environmental Earth Sciences**, v. 79, n. 11, p. 1–15, 2020.

GHILARDI, M. Geoarchaeology: Where geosciences meet the humanities to reconstruct past human–environment interactions. an application to the coastal areas of the largest mediterranean islands. **Applied Sciences (Switzerland)**, v. 11, n. 10, 2021.

GLASER, B. et al. Black carbon in density fractions of anthropogenic soils of .pdf. **Organic Geochemistry**, v. 31, p. 669–678, 2000.

GMACH, M. R. et al. Processes that influence dissolved organic matter in the soil: a review. **Scientia Agricola**, v. 77, n. 3, 2020.

KERN, J. et al. What can we learn from ancient fertile anthropic soil (Amazonian Dark Earths, shell mounds, Plaggen soil) for soil carbon sequestration? **Catena**, v. 172, n. February 2018, p. 104–112, 2019.

KÖGEL-KNABNER, I.; AMELUNG, W. Soil organic matter in major pedogenic soil groups. **Geoderma**, v. 384, n. March 2020, 2021.

LIANG, B. et al. Black Carbon Increases Cation Exchange Capacity in Soils. **Soil Science Society of America Journal**, v. 70, n. 5, 2006.

LOMBARDO, U., Iriarte, J., Hilbert, L. et al. Early Holocene crop cultivation and landscape modification in Amazonia. **Nature.** 581**,** 190–193, 2020.

MACEDO, R. S. et al. Pedogenetic processes in anthrosols with pretic horizon (Amazonian Dark Earth) in Central Amazon, Brazil. **PLoS ONE**, v. 12, n. 5, p. 1–19, 2017.

MACHADO, M. R. et al. <b>Land cover changes affect soil chemical attributes in the Brazilian Amazon. **Acta Scientiarum. Agronomy**, v. 39, n. 3, 2017.

MAYER, S. et al. Controlling factors of organic carbon stocks in agricultural topsoils and subsoils of Bavaria. **Soil and Tillage Research**, v. 192, n. January, p. 22–32, 2019.

MIKUTTA, R. et al. Stabilization of soil organic matter: Association with minerals or chemical recalcitrance? **Biogeochemistry**, v. 77, n. 1, p. 25–56, 2006.

MUSTAFA, A. et al. Soil aggregation and soil aggregate stability regulate organic carbon and nitrogen storage in a red soil of southern China. **Journal of Environmental Management**, v. 270, n. February, 2020.

NEGREIROS, R. DE S. et al. Caracterização mineralógica de terra preta das Comunidades do Marajó e Gregostone, em Parintins, Amazonas, Brasil / Mineralogical characterization of black earth from the Marajó and Gregostone communities, in Parintins, Amazonas. **Brazilian Applied Science Review**, v. 4, n. 5, p. 2882–2894, 2020.

NEJMAN, L. et al. Cave deposits as a sedimentary trap for the Marine Isotope Stage 3 environmental record: The case study of Pod Hradem, Czech Republic. **Palaeogeography, Palaeoclimatology, Palaeoecology**, v. 497, 2018.

NEJMAN, L. et al. Preliminary report of the 2019 excavation at švédův stůl cave in the Moravian Karst. **Prehled Vyzkumu**, v. 61, n. 1, p. 11–19, 2020.

SALISBURY, R. B. Advances in archaeological soil chemistry in Central Europe. **Interdisciplinaria Archaeologica**, v. 11, n. 2, 2020.

SALTON, J. C. et al. Agregação do solo e estabilidade de agregados. In: TEIXEIRA, P. C. et al. (Eds.). . **Manual de Métodos de Análise de Solo**. 3. ed. Brasília, DF: [s.n.]. p. 129–138.

SANTANA MACEDO, R. I. et al. Amazonian dark earths in the fertile floodplains of the Amazon River, Brazil: an example of non-intentional formation of anthropic soils in the Central Amazon region Terra Preta de Índio em várzeas eutróficas do rio Solimões, Brasil: um exemplo da não int. **Bol. Mus. Para. Emílio Goeldi. Cienc. Hum**, v. 970, n. 1, p. 207–227, 2019.

SANTOS, L. A. C. DOS et al. Pedogenesis in an Archaeological Dark Earth – Mulatto Earth Catena over Volcanic Rocks in Western Amazonia, Brazil. **Revista Brasileira de Ciência do Solo**, v. 42, n. 0, p. 1–18, 2018.

SILVA, L. C. R. et al. A new hypothesis for the origin of Amazonian Dark Earths. **Nature Communications**, v. 12, n. 1, 2021.