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Spatial variability of soil physical properties in Archeological Dark Earths under different uses in southern Amazon

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ABSTRACT

The Amazon region has soils of an anthropic formation called Anthropogenic Dark Earths (ADEs). These soils present a higher fertility and are physically different to adjacent local soils. This study aimed to investigate the conditions and spatial behavior of soil physical attributes in ADE areas cultivated with cocoa, coffee, and grassland in southern Amazon. Mapping of three ADE areas was carried out by using sampling grids of 80 m × 56 m with regular spacing of 8 m for the grassland area and 48 m × 88 m with a spacing of 6 m × 8 m for the cocoa and coffee areas. These soils were sampled at the grid crossing points at depths of 0.00–0.05; 0.05–0.10 and 0.10–0.20 m, totaling 88 points in each area. Soil physical analyses of texture, macroporosity, microporosity, total porosity, bulk density, θFC (moisture field capacity), penetration resistance, and aggregate stability were carried out. The data were submitted to descriptive statistics, geostatistics, and multivariate statistics. In the ADE area cultivated with grassland, the attributes showing moderate and weak levels of spatial dependence were those with a greater spatial continuity, i.e. texture, penetration resistance, macroporosity, microporosity, and volumetric moisture. A similar behavior was observed in the ADE areas cultivated with coffee (sand, density, penetration resistance, macroporosity, and microporosity) and cocoa (silt, clay, penetration resistance, macroporosity, and mean weight diameter of aggregates).

1. Introduction

In the Amazon region, soils of black earth are commonly found in the landscape, being called by natives as classified by archaeologists as Anthropogenic Dark Earths (ADEs), which are considered as modified soils from those pre-existing via prehistoric human activities (Costa et al., 2004). The geographical distribution of ADEs occurs in the form of discontinuous patches throughout the Amazon, being associated with watercourses, such as floodplains, and well-drained environments or locations with a favorable topographic position (German, 2003). Studies have pointed out that nearly 0.1 to 0.3% of the Amazon basin is occupied by ADE areas, with sites varying from less than 1 ha (ha) on elevated terraces parallel to the rivers to 400 ha (ha) (Sombroek et al., 2003).

ADEs are soils with a dark color, high natural fertility, high P, Ca, and Mg contents, the presence of ceramic and/or lytic fragments incorporated to their more superficial horizons (Kämpf and Kern, 2005), as well as higher biological activity when compared to adjacent soils (Glaser, 2007). The physical attributes of these soils vary much between ADE sites (Teixeira et al., 2009). The texture goes from sandy to very clay (Lima et al., 2002). They have well-drained horizons with good water availability, low soil bulk density, and good conditions of aeration, porosity, and hydraulic conductivity, in addition to promoting water infiltration and gas exchange (Neves Junior, 2008).

The knowledge of the spatial distribution of soil attributes in natural and anthropic environments has a great importance since their formation processes over time and human management may accentuate their variability (Oliveira et al., 2015). In this sense, geostatistical analysis has allowed detecting the presence of variability and spatial distribution of soil variables, making it an important tool in the analysis, and detailed description of soil attributes (Campos et al., 2007). In addition, the study of spatial dependence has been presented as an alternative to reduce the effects of soil variation on crop production and estimate the responses of soil attributes due to certain management practices (Souza et al., 2004).

Studies have shown the importance of physical attributes in

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anthropic soils and their possible use in agriculture since the Amazon region presents a high agricultural potential due to the presence of these anthropogenic soils (Siqueira et al., 2009). Thus, the aim of this study was to determine the condition and spatial behavior of soil physical attributes in Anthropogenic Dark Earth areas cultivated with coffee, cocoa, and grassland in southern Amazon.

2. Material and methods

2.1. Characterization of the study area

The study was conducted between August 2015 and June 2016. The ADE areas cultivated with cocoa, coffee, and grassland are located in Apuí and Manicoré, southern Amazonas State, Brazil, close to the Transamazônica highway (BR 230). The parent material is from the alteration of Rondonianos granites, from the Upper Precambrian, with colluvial sediments deposited in the landscape lower parts and tertiary coverings (Brasil, 1978). Regional climate is Am type according to Köppen classification, i.e. a tropical rainy climate with a dry period of short duration, temperatures from 25 to 27 °C, and precipitations between 2250 and 2750 mm concentrated from October to June (Brasil, 1978). The characteristic regional vegetation is a dense tropical forest consisting of densified and multi-stratified trees with a height of 20 to 50 m (ZEE-AM, 2008).

The ADE area cultivated with grassland is located in Manicoré and presents geographical coordinates of 7°59′22″ S and 61°39′51.2″ W and an average altitude of 83 m. The area was cultivated with "*Brachiaria brizantha*" (Marandu cultivars) with approximately seven years of extensive grazing and supporting capacity of about one unit/animal per hectare (Fig. 1). The soil was classified as a Argissolo Vermelho Amarelo Eutrófico (Campos, 2009) or Ultisol in the USDA classification (Typic Haplohumult, Soil Survey Staff, 2014) and the regional primary vegetation is characterized as a dense tropical forest.

The ADE areas cultivated with cocoa and coffee (*Coffea canephora*) are located in Apuí and present geographical coordinates of 7°12′05″ S and 59°39′35″ W. Cocoa has been cultivated in the area for 14 years and had rice, corn, beans, and watermelon cultivated in the same area in the first six years (Fig. 1). Coffee has been cultivated in the area for six years and had grassland cultivated in the same area in the first two years. No machinery was used in the implantation and maintenance of the cultivated areas. The soil of both ADE areas was classified as a Argissolo Vermelho Eutrófico (Embrapa, 2013) (Typic Haplohumult, Soil Survey Staff, 2014).

2.2. Field and laboratory methodology

A sampling grid of 80 m × 56 m with a regular spacing of 8 m was installed in the grassland area and grids of 48 m × 88 m with a spacing of 6 m × 8 m were installed in the cocoa and coffee areas. Soils were sampled at the grid crossing points at depths of 0.00–0.05; 0.05–0.10 and 0.10–0.20 m, totaling 88 points and 264 soil samples for each cultivation system. All points were georeferenced with a GPSMAP 76CS (Garmin International, USA) (accuracy of < 10 m) aiming at constructing a digital elevation model (DEM).

Particle size distribution was analyzed in the laboratory with 1.0 mol L^{-1} NaOH solution as chemical dispersant and rest of 16 h. The suspension was transferred to metal beakers with water, being coupled to an electric stirrer at 12,000 RPM for 15 min (Embrapa, 2011). Clay fraction was separated by the pipette method, sand by sieving, and silt calculated by their difference.

Undisturbed samples of soil were collected for the analysis of macroporosity, microporosity, total porosity, bulk density, and θ field capacity (θFC). These samples were collected by soil core with an average volume of 98.36 cm^3 at depths of 0.00–0.05; 0.05–0.10 and 0.10–0.20 m. The samples were prepared in the laboratory by removing the excess of soil from the soil core edges; they were then saturated by a gradual increase in water depth until reaching approximately 2/3 of the soil core height.

Total porosity was determined by the saturation method. Macroporosity was obtained from the balance of the set soil core-soil after applying −6 kPa in a tension table. In its turn, microporosity was obtained by subtracting the weight of the Soil core-soil set equilibrated at −6 kPa and its respective oven-dried weight at 105 °C. The θFC was obtained by the difference between the wet soil mass and the dry soil mass in an oven at 15°C for 24 h (Embrapa, 2011).

Soil penetration resistance (PR) to root was determined in the laboratory with the same soil core after determining macroporosity. In this case, a Marconi electronic penetrometer model MA–933 was used at a constant velocity of 0.1667 mm s^{-1}. This device was equipped with a 200 N load cell, a 4-mm conical rod, and at a 30° semi-angle, with a receiver and interface coupled to a microcomputer to record the readings (Petean et al., 2010). For each sample, 290 values were obtained, eliminating the 30 initial and final ones.

Bulk density was determined after PR tests by the soil core method as described in Grossman and Reinsch (2002). In this case, the soil in the soil core was oven dried at 105 °C until constant weight.

Clods with their preserved structure were also collected from each sampling point to determine soil aggregate stability via dry. These samples were shade-dried, lightly manually crushed, and passed through a 9.51 mm sieve to be retained on the 4.76 mm sieve. Separation and aggregate stability were determined according to Kemper and Chepil (1965) (with modifications) in the diameter classes > 2.0 and < 2.0 mm. The aggregates from the sieve of 4.76 mm were placed on a water-based Solotest Yoder sieve stirrer on a 2-mm sieve for 15 min. The mass of material retained on each sieve used (2; 1; 0.5; 0.25; 0.125 and 0.063 mm) was placed in containers and subsequently in an oven at 105 °C. The results were expressed in mean weight diameter (MWD) and mean geometric diameter (MGD).

2.3. Descriptive statistics and geostatistics analyses

The data were submitted to analysis of variance and the means compared using the Tukey's test at 5%, followed by descriptive statistics, i.e. mean, amplitude (between maximum and minimum), coefficient of variation, coefficients of asymmetry and kurtosis, and Kolmogorov-Smirnov normality test performed in the statistical software Minitab Release 14 (Minitab, 2000). The coefficient of variation (CV%) was assessed according to the Warrick and Nielsen (1980) classification, as follows: CV < 12%; 12 < CV < 60%, and CV > 60% for low, medium, and high variability, respectively.

The geostatistics analysis was used for characterizing the spatial variability of soil attributes by means of the software GS^+ version 7.0 (Robertson, 1998). Under the intrinsic hypothesis theory, the experimental semivariogram was estimated by Eq. (1).

$$\hat{\gamma}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i + h)]^2 \quad (1)$$

where γ(h) is the value of semivariance for a distance h, N(h) is the number of pairs of points involved in the semivariance calculation, $Z(x_i)$ is the value of the attribute Z in the position x_i, and $Z(x_i + h)$ is the value of attribute Z separated by a distance h from the position x_i.

For the mathematical model adjustment to the calculated values of γ(h), coefficients of the theoretical model are defined for the semivariogram (nugget effect or C_0, sill or C_1, structural variance or $C_0 + C_1$, and range or a). The nugget effect is the semivariance value for distance 0 and simulates the random variation component, the sill is the semivariance value at which the curve stabilizes over a constant value, and the range is the distance (in meters) from the origin to where the sill reaches stable values.

The semivariogram parameters were used for classifying the degree of spatial dependence (DSD), as proposed by Cambardella et al. (1994),