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Multivariate approach of soil attributes on the characterization of land use in the southern Brazilian Amazon

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A R T I C L E I N F O

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A B S T R A C T

Determination of physical, chemical and biological attributes with individual analyses is inadequate for improving the understanding of soil conditions as a function of land-use change (LUC) in comparison to the natural state of soil. For a more accurate soil condition diagnostic, it is necessary to consider various indicators related to these characteristics, which requires the use of multivariate statistical analysis. The aim of this work was to characterize, through multivariate analysis, different types of LUCs in an Oxisol as a function of the physical, chemical and biological attributes and to clarify the relationship of these attributes with the quality of the soil in comparison to these attributes in natural soil conditions, in the southern Amazon in Brazil. The land uses evaluated in the municipality of Alta Floresta, state of Mato Grosso (MT), Brazil, were native amazon forest (ma), degraded pasture (pd), managed renewed pasture (pn), permanent preservation area in recovery (app), crop area (rice), forage sugarcane (ca) and reforested area with eucalyptus (eu). To characterize the physical and chemical soil attributes, samples were collected in each land-use area, at depths of 0-0.10 and 0.10-0.20 m, and the determination of soil microbial activity (biological attributes) was evaluated at a depth of 0-0.10 m. The interrelationship between the analyzed attributes was described by multivariate techniques, which included hierarchical and non-hierarchical cluster analyses, principal component analysis, canonical correlation, and structural equation modeling. The multivariate approach for the analysis of soil attribute data was efficient in the identification of anthropogenic actions on areas in comparison to natural conditions. Together, the cluster analysis and principal components analysis identified two groups that differed mainly in terms of anthropic operations of soil tillage and liming. The land use that was most similar to the natural condition was degraded pasture, which was mainly due to K and H + Al contents, soil microporosity and soil basal respiration. Structural equation modeling indicated that the latent factor soil chemical attributes had three times greater interference (-0.5828) than the latent factor soil physical attributes (0.1735) on the latent factor soil biological attributes. Therefore, anthropic actions, especially the liming, modified soil acidity conditions, affecting the microorganisms of its flora and changing the native fungal community of the soil that was evaluated.

1. Introduction

The loss of native vegetation coverage, land-use change (LUC), and the inappropriate use of soil have led to the degradation of natural resources and reduction of soil quality related to its physical, chemical and biological attributes (Rojas et al., 2016). The economic and social pressure for food production, as well as the inappropriate and unplanned exploitation of natural resources, have caused degradation in large areas, mainly through the inadequate conversion of natural environments into agricultural areas (Fonseca et al., 2007; Rojas et al., 2016). The main impact of LUC is on in the soils, which are directly responsible for the sustainability and productivity of natural and agricultural ecosystems (Castilho et al., 2016; Novak et al., 2017; Sanabria et al., 2016).

Studying the physical, chemical and biological attributes of soil in different applications and comparing these attributes to those in areas

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without anthropic action makes it possible to quantify the magnitude of the changes that have occurred due to different models of exploitation (Brookes, 1995; Gomes et al., 2016). According to Reicher et al. (2009), based on the sensitivity of these attributes, it is possible to establish the occurrence of degradation or improvement of soil quality compared to soil in a non-anthropized environment. According to Doran et al. (1994), good levels of these attributes provide ideal conditions for the growth and development of plants and favor maintenance of diversity of the organisms that exist in the soil. Currently, there are several techniques and methodologies used to evaluate soil microbial activity, such as enzymatic activity and genetic fingerprinting. However, techniques that characterize soil basal respiration (SBR) and carbon levels of microbial biomass (MBC) are preferable due to the ease of their application and lower costs; hence, these techniques are considered as important tools in understanding changes in soil organic compartments.

In addition, it should be stressed that existing interrelations among the physical, chemical and biological attributes control the processes and aspects related to variance with time and space. Therefore, changes in the structure of the soil and in its biological activity and fertility may have impacts on agroecosystems, such as damage to soil quality and productivity of crops (Brookes, 1995). Knowing the modifications that occurred in the soil caused by its use provides information that can help adapt management practices to enable crop output to be increased, which thereby ensures the sustainability and conservation of the agroecosystem.

Considering the soil as a complex system, resulting from the interaction of geological, topographical and climate factors, among others, which together form indicators that characterize the soil, it is possible to use multivariate analysis techniques to more efficiently explore the correlations among these variables and determine those that contribute more to soil characterization and/or soil changes (Gong et al., 2015; Khaledian et al., 2017; Pragana et al., 2012; Rojas et al., 2016). Nazmi (2013) used multiple linear regression models and equation modeling with the aim of correlating latent factors (factors that are not observable on the field but are associated with correlated attributes observed on the field) and determining the influence of these factors on the physical, chemical and production attributes of wheat. It was concluded that the measurements of physical and chemical attributes were statistically significant for predicting and understanding the components of wheat production using regression and structural models. Therefore, multivariate techniques are promising for studies of land-use and management practices that influence the quality and health of the soils. Research with the aim of understanding indicators of soil quality that best explain the changes that have occurred due to soil use may contribute to enhancing soil quality if appropriate practices are employed. Given this context, the objective of this work was to characterize different soil uses in the southern Amazon, as a function of the physical, chemical and biological attributes to identify which key properties can be used to characterize the soil, as well as to establish the interrelation of the soil attributes with soil' quality and natural conditions of the systems, using multivariate techniques, mainly structural equation modeling.

2. Materials and methods

2.1. Area of study

The field experiment was carried out in the rural property named the Maringá Farm, located in Alta Floresta, on the MT 206 road km 165, whose geographical coordinates are 9° 50′ 23.86″ south latitude and 56° 13′ 22.89″ west longitude and is located at 280 m above sea level (Fig. 1). The region has a rainy tropical climate, type Am according to the Köppen classification, with short dry periods and long rainy periods, temperatures range from 25 to 27 °C, and the average precipitation is 2243 mm. The soils of the experimental areas are classified as Oxisols. The terrain was classified as moderately flat.

The land uses selected were the following: native forest area (ma), characterized as dense ombrophylous forest, with an area of 11.5 ha; degraded pasture (pd) with *Brachiaria brizantha* since 1993 and with 5 years of fertilization at 120 kg ha^{-1} of Thermophosphate (16.5% of P_2O_5), with an area of 10.5 ha; renewed pasture (pn), cultivated with *Brachiaria brizantha* since 2016 with an application of 150 kg of mono-ammonium-phosphate (MAP) and 3.0 Mg ha^{-1} of limestone, with an area of 26.3 ha; permanent preservation area (ppa) in recovery, which was established with *Brachiaria brizantha* in 1993, and in 2014, the pasture was eliminated and primary and secondary native forest species were introduced for reforestation, with an area of 5.1 ha; farming area (la), which had contained *Brachiaria brizantha* since 1997 but was eventually removed, with conventional soil tillage (plow) to carry out rice planting, with a seeding fertilization of 150 kg ha^{-1} of mono amino phosphate (MAP-10% of N and 50% of P_2O_5) and an application of 120 kg ha^{-1} of 20-00-20 on the covering, harvest occurred in 2016/2017, with an area of 22.5 ha; forage sugarcane area (ca), whose planting was performed in 2003, with an application of limestone at 2.5 Mg ha^{-1} and fertilization of 120 kg ha^{-1} of $N:P_2O_5:K_2O$ (00-20-20), annual covering fertilization with 120 kg ha^{-1} of 20:00:20, and previously, the area had contained *Brachiaria brizantha* since 1993, with an area of 7.6 ha; reforestation area (eu) with eucalyptus since 2012, without any type of fertilization or limestone application, and the area had contained *Brachiaria brizantha* since 1997, but it was eventually removed, with conventional soil tillage (plow), with an area of 4.5 ha (Fig. 1). An evaluation of the native forest area (Amazon Forest) was used as a reference for the analysis because it represents the conditions before anthropic actions.

2.2. Determination of the soil's biological, physical and chemical attributes

The collection of soil samples was made with the aid of an auger, totaling ten repetitions, at the 0-10-m layer in each treatment. In the field, the samples were kept in styrofoam coolers with ice until their transportation to the Laboratory of Soils and Foliar Analysis of the University of Mato Grosso State – UNEMAT, Campus of Alta Floresta, where they were sieved (2 mm) and kept under refrigeration until the analyses were made. The analysis was based on the procedures proposed by Silva et al. (2007a) for determining the soil basal respiration (SBR), and the determination of its microbial biomass carbon (MBC) was performed according to the recommendations of Silva et al. (2007b).

The analyses were made at the Laboratory of Soils and Foliar Analysis at the University of Mato Grosso State – UNEMAT, Campus of Alta Floresta. To determine the porosity of the soil, the tension table method was employed, which was adapted from Kiehl (1979). The non-deformed soil samples were properly prepared (the inner surface of the ring was protected with a tissue that was slightly larger than the ring's diameter, such that the excess bent over the ring's surface and was tied with an elastic band) and saturated through the gradual elevation of a water blade on a tray, until it attained 2/3 of the samples' height, according to Embrapa (1997). Then, the following analysis procedures were conducted. After being saturated, the samples were placed upon the tension table, the level vial was lowered to the level of suction corresponding to 0.60 m of water column height (-0.006 MPa), and then, water from the macropores was removed (% of pores with diameter of 0.05 mm). After being weighed, before (saturated) and after the table (until draining stopped, when a constant weight is attained for the sample), the volume of the macropores was determined using Eq. (1) (EMBRAPA, 1997).

$$Ma = \left(\frac{W\ saturated - W\ after\ tension\ table}{Total\ volume}\right) \times 100 \quad (1)$$

After removing the water from the macropores (% of pores with diameter of 0.05 mm), the samples were dried in greenhouse circulation