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# SPATIAL VARIABILITY OF PHYSICAL ATTRIBUTES, LITTER AND SOIL CARBON STOCK IN A FAMILY FARMING SYSTEM IN TOCANTINS[1]

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**Keywords:**
geo-statistics
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**ABSTRACT**

The monitoring of soil attributes allows the evaluation of its ability to perform its functions within an agroecosystem. The objective of this work was to evaluate the spatial variability of soil physical attributes, litter and carbon stock in a family farming system in the Cerrado Tocantinense. The area is located in the southern region in the state in the municipality of Aliança do Tocantins. Four types of land use were diagnosed in the area: brachiaria pasture intercropped with stylosanthes, Andropogon pasture, orchard and native forest. The native forest was considered as a reference. The study area totaled 7.9 $ha^{-1}$ in which it was distributed an irregular sample grid composed of 160 points. Deformed and undeformed samples were collected for each georeferenced point at depths of 0-10 and 10-20 cm, as well as samples to determine the litter and soil carbon stock. Data were submitted to exploratory analysis and geostatistical study. It was found that the conversion of native forest for different soil uses through orchard, brachiaria, andropogon and native forest caused spatial variability in physical attributes, litter and soil carbon stock at depths 0-10 and 10-20 cm. The orchard subarea stood out as a promising system in the accumulation of organic carbon due to cattle manure.

**Palavras-chave:**
geoestatística
manejo
qualidade do solo

## VARIABILIDADE ESPACIAL DE ATRIBUTOS FÍSICOS, LITEIRA E ESTOQUE DE CARBONO EM SOLO DO CERRADO TOCANTINENSE

**RESUMO**

O monitoramento dos atributos do solo possibilita avaliar a capacidade do mesmo em exercer suas funções dentro de um agroecossistema. Objetivou-se com esse trabalho avaliar a variabilidade espacial de atributos físicos, liteira e estoque de carbono do solo sob sistema de agricultura familiar no cerrado tocantinense. A área está localizada no município de Aliança do Tocantins, sul do Estado. Foram diagnosticados quatro tipos de uso do solo na área: pastagem de braquiária consorciada com estilosantes, pastagem de Andropogon, pomar e mata nativa. A mata nativa foi considerada como referência. A área de estudo totalizou 7,9 $ha^{-1}$, na qual foi distribuída uma malha amostral irregular composta por 160 pontos. Para cada ponto georreferenciado coletaram-se amostras deformadas e indeformadas nas profundidades de 0-10 e 10-20 cm, além de amostras para determinação da liteira e estoque de carbono do solo. Os dados foram submetidos à análise exploratória e ao estudo geoestatístico. Constatou-se que a conversão da mata nativa para os diferentes usos do solo através do pomar, braquiária, andropógon e mata nativa ocasionaram variabilidade espacial nos atributos físicos, liteira e estoque de carbono do solo nas profundidades 0-10 e 10-20 cm. A subárea de pomar se destacou como sistema promissor no acúmulo de carbono orgânico devido ao esterco bovino.



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## INTRODUCTION

Soil quality varies according to its natural composition and is also strongly related to interventionist practices. Among the properties of the soil, the physical characteristics are those that perform the main functions, so their knowledge is important for a better support to the proper use and management of the soil. In this sense, unlike precision agriculture, family farming, with its importance for the country, is lacking studies on spatial variability in its production systems.

The soil has both vertical and horizontal heterogeneity, depending on the nature of the factors responsible for its formation. Studies report that the variability of soil physical properties showed correlation or spatial dependence (GUIMARÃES *et al*., 2016; MILAGRES *et al*., 2018). The attributes soil density, texture, structure, porosity, soil penetration resistance, litter and soil organic matter have been used as indicators for soil quality measurement.

According to Lima *et al*. (2006), the study of soil density has been currently prioritized to evaluate soil use and management systems, as it is an easily determined attribute that is directly related to plant growth and development, and serves as an indicator of compacted areas. On the other hand, according to Cardoso (2014), texture, structure, porosity and soil resistance to penetration, are directly related to the infiltration capacity, retention and availability of water and nutrients to plants, gas exchange of the atmosphere with the roots and growth and vegetal development with no impediments.

Litter is another attribute that decisively contributes to the physical properties of the soil (SATTLER, 2006), thus interfering in the spatial variability of soil fertility. The accumulated litter in the soil corresponds to the nutrient and organic matter reservoir that influences and regulates many ecosystem functional processes (SPERANDIO *et al*., 2012).

Soil organic matter is considered as an indicator of quality, exerting biological, physical and chemical functions and processes that occur in the soil (VEZZANI and MIELNICZUK, 2009). It must be stressed that 58% of soil organic matter is made up of organic carbon. Quantifying it allows organic carbon to be estimated, and vice versa. Thus, most studies on soil organic matter are strongly linked to the quantification of soil carbon stocks. In addition, organic matter is efficient for monitoring changes in soil quality over time in addition to being sensitive to management changes (OLIVEIRA *et al*., 2015).

Therefore, the conventional tillage system with continuous soil tillage presents a significant decrease in organic matter when compared to no-tillage (TEIXEIRA *et al*., 2010). The no-tillage system results in the maintenance or addition of soil organic matter contents (SALTON *et al*., 2011), as they directly contribute to the improvement of cation exchange capacity, nutrient availability and construction of soil aggregation (SRINIVASAN *et al*., 2012).

However, it should be considered that the evaluation of soil attributes as quality indicators is complex, due to the diversity of uses and aspects related to their variation in space, among other factors (MELLONI *et a*l., 2008). Therefore, an efficient soil quality monitoring must take into account spatial variability. Information on spatial variability of attributes such as soil density, texture and organic matter is crucial for decision making in research, ecosystem and agriculture management (PONGPATTANANURAK *et al*., 2012).

In this sense, studies with spatial variability allow the detection of variations in physical attributes found in the soil and its random aspects, the creation of images that demonstrate the variability of the characters, the identification of the magnitude and degree of spatial dependence, and finally, they provide information that allow subsidizing the study of the phenomenon to be analyzed (SILVA NETO *et al*., 2011). This tool has been commonly used in the detection of places that show some alteration in relation to the natural condition and, based on that, allow determining the conditions of cause and effect, and possible measures of restoration of the environment.

Thus, the objective of this study was to evaluate the spatial variability of the attributes soil density, sand, silt, clay, organic carbon stock and litter in a family farming system under different agricultural uses.

## MATERIAL AND METHODS

The study was carried out at the Arlindo Settlement Project - Chácara Três Poderes, municipality of Aliança do Tocantins. The site is located at 280 m above sea level within the coordinates 11°13'30" S latitude and 48°55'20" W longitude. The annual rainfall is 1,617 mm, with Aw climate (tropical with dry winter). It has a rainy season in summer from November to April and a clear dry season in winter from May to October, according to Köppen and Geiger (1928). According to the Brazilian Soil Classification System, the soil is classified as a typical Petroferric Eufrophic Alfiso, which is characterized by the presence of an iron oxide concretion layer, which is an obstacle to root penetration and soil tillage. However, the soil has no restrictive characteristics at the fourth classification level (EMBRAPA, 2014).

The site has been under agricultural use for 20 years, except the native forest (native *Cerrado*) subarea. The area is divided into four use and management systems: brachiaria (*Urocloa brizantha* cv. Marandu) pasture associated with stylosanthes (*Stylosanthes* spp.) (B), andropogon (*Andropogon gayanus*) pasture (A), orchard (P) and native forest (M). It is noteworthy that in the grazing subareas, the grazing is rotated, with a capacity of 1.89 animals ha$^{-1}$. The native forest subarea was considered as a control and allowed to infer if the other uses changed the soil.

Figure 1 shows the site and types of land use in the area.

The brachiaria pasture subarea associated with stylosanthes is six years old and has 2.11 ha$^{-1}$. The management of the subarea consisted of the application and incorporation into the soil of four tons of limestone, harrowing, and application of 750 kg of 5:25:15 manure in 2011. The pasture renewal occurred every year naturally, and weed management was done by manual mowing. In this subarea, in the previous year, Napier grass

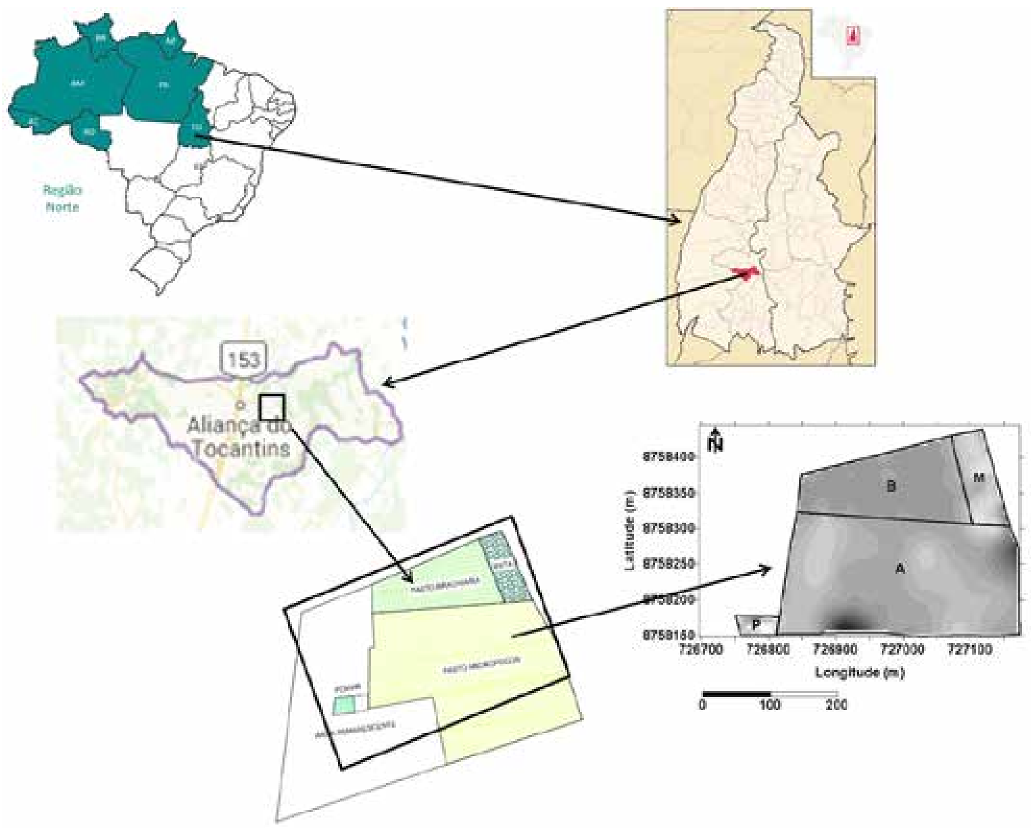


**Figure 1.** Location of the area under the use of brachiaria pasture (B), native forest (M), orchard (P) and andropogon grass pasture (A).

(*Pennisetum purpureum*) was cultivated for cattle feeding.

The andropogon subarea has 5.01 $ha^{-1}$ and 20 years of implementation. The applied management was burning followed by the planting of the grass. Weed control was carried out whenever necessary through manual mowing. The establishment and renewal of the pasture every year took place naturally. No acidity correction, fertilization or soil tillage was performed.

The orchard area has 0.12 $ha^{-1}$. Part of the subarea is 14 years old and the other has been recently implemented. The species found in the area are as follows: cashew (*Anacardium occidentale* L.); mango (*Mangifera indica* L.) and *jamão* (*Syzygium cumini*). Soil correction nor mineral fertilization at planting or maintenance were performed. Weed management was manual, both in the crop implantation phase and in the post-planting crop treatments. The plants were subjected to maintenance pruning whenever necessary. It is noteworthy that the area is a resting place for cattle and therefore has specific areas with significant amount of organic matter from cattle manure.

The native forest subarea has 0.67 ha and represents the natural condition of the soil. No anthropic intervention was found in the area. Shrubs and trees make up the predominant vegetation.

**Soil sampling**

The area totaled 7.91 ha, in which an irregular sample grid composed of 160 points was distributed, as performed by Oliveira et al. (2008), in which they were obtained through the Global Positioning System (GPS).

The samples were collected in the 0-10 and 10-20 cm deep layers (EMBRAPA, 2011) and the analyses were performed in the Soils and Soil and Water Quality Laboratories of the Federal University of Tocantins (UFT).

Soil Density (SD), particle size (sand, silt and clay), litter and soil organic matter (SOM) values were measured. The separation and determination of granulometric fractions (sand, silt and clay) were performed according to the methodology described by Embrapa (2011). The pipette method was used, with 1 mol $L^{-1}$ NaOH as the dispersing chemical agent. Significant amount of gravel was also observed, which was used as a modifier of the textural grouping, according to Embrapa (2014). Santos *et al*. (2013), recognizes three classes regarding the proportion of gravel in relation to the fine earth, and according to the classification of these authors, the area of the present study is classified as gravelly (gravel content between 150 and 500 g $kg^{-1}$). Thus, as for texture, the classification for the studied area varies from medium to gravelly sandy (EMBRAPA, 2006).

The deformed samples (granulometric fractions - sand, silt and clay and, SOM), were removed through destruction or appreciable modification of their characteristics in situ. To obtain Organic Carbon (OC), the SOM values were divided by 1.724, according to Ribeiro et al. (1999). The undisturbed sample (Bulk Density) was obtained by the volumetric ring method (EMBRAPA, 2011). After collection, they were taken to the laboratory and stored in an oven at 105º C for 24 hours. After this period, the weighing (cylinders + sample) was carried out.

The values of OC and BD allowed to estimate values of Carbon Soil Stock (CSS), calculated through Equation 1.

$$CSS = \frac{OC * BD * d}{10} \tag{1}$$

In which,

CSS = carbon soil stock (t $ha^{-1}$);
OC = soil organic carbon content (g $kg^{-1}$);
BD = bulk density (g $cm^{-3}$); and
d = soil layer depth (cm).

The content of SOM was determined by means of the Mufla method (GOLDIN, 1987). First, the crucibles were oven dried at 60°C for one hour to tare. Subsequently, the samples (5g of soil) were oven dried at 110°C for 3 hours in order to eliminate all water in the residue. After obtaining the weight of the samples dried at 110°C, the ceramic crucibles with the samples were placed in a muffle furnace at a temperature of 550°C for one hour after stabilization of the equipment. Subsequently, the set (crucible + residue) was taken to the desiccator and remained in there until the samples reached room temperature so that they could be weighed. The organic matter content was determined as a result of the loss of mass of the incinerated residue, considering the material lost by burning in the temperature range of 110 to 550 ° C, according to Equation 2:

$$OM\ (\%) = \frac{W - (T - C) \times 100}{W} \qquad (2)$$

Where,

OM (%) = organic matter content;
W = weight of the sample (g) after heating at 110° C;
C = crucible tare (g); and
T = ash weight + tare (g).

For litter collection, an area of 0.25 x 0.25 m was considered at points adjacent to the soil sample collection. The collected material was submitted to drying in a forced air oven at 60ºC for 72 hours. After drying, the material was weighed on an electronic precision scale (0.01g), and the result obtained in grams (g).

**Data analysis**

The values of the variables (clay, sand, silt, Bulk Density, Litter and Soil Carbon Stock) at 0-10 cm and 10-20 cm depths were initially submitted to exploratory analysis to verify if they occurred random or aggregate, so the mean, median, mode, asymmetry coefficient ($C_s$), kurtosis coefficient ($C_k$), and coefficient of variation (CV) were calculated.

The hypothesis of data normality was verified with the Shapiro and Wilk (1965) test at the 1 and 5% probability level with the aid of SISVAR, software version 5.3 (Build 77).

Data normality is not considered a premise for the application of geostatistics in the study of spatial variability (CORÁ & BERALDO, 2006). However, data sets that present normal distribution allow better adjustment of the semivariogram, besides facilitating the process of its adjustment (MACHADO *et al*., 2007). In addition, according to Paz-Gonzales *et al*. (2001), when the normality of the data is satisfied, the estimation of values not sampled by the Kriging method becomes more efficient and accurate, and offers better results.

The coefficients $C_s$ and $C_k$ are associated with standard error and tend to have distributions close to symmetrical and normal. According to Negreiros Neto et al. (2014), to assume that a distribution is normal, $C_k$ values should preferably be null, however, when between +2 and -2 they can be accepted. Webster (2001) states that asymmetry values up to 0.5 indicate that a given attribute has a normal distribution in order to dispense data transformation.

As an auxiliary tool to obtain these parameters, the software GS + v 7.0 (Build 17) was used. The coefficient of variation (CV) limits classified as low (CV <12%), medium (12 <CV <60%) and high (CV> 60%) proposed by Warrick and Nielsen (1980) were adopted. The spatial variability of the variables was evaluated with the aid of the geostatistical tool. Initially, data were adjusted to the experimental semivariogram according to the theory of regionalized variables, with the aid of the GS+ v. 7.0 (Build 17) software. The semivariograms were adjusted to theoretical mathematical models – spherical, exponential, linear and Gaussian – to define the nugget effect (C0), range and plateau ($C + C_0$) values. The coefficient $C_0$ represents the unexplained variance, usually derived from measurement errors or variations that were not detected in the sampling scale. The range, that is, the maximum distance at which each variable is spatially correlated, was compared for the different evaluated variables. High range values provide more accurate and reliable ordinary krigging interpolation, and the creation of maps that represent the reality of the study area more accurately due to the influence exerted on the number of values used in the interpolation (CORÁ & BERALDO, 2006). The relations between nugget effect ($C_0$) and plateau ($_{C0}$ + C) show predominance of Degree of Spatial Dependence (DSD). The DSD of the variables was determined as a function of equation (3).

$$DSD = [C / (CO + C)] * 100 \qquad (3)$$

Where,

DSD (%) = Degree of Spatial Dependence;
$C_0$ = nugget effect;
C = contribution (plateau– nugget effect); and
$C_0$ + C = plateau.

Once the result of Equation 3 is obtained, it is possible to classify the DSD into: weak spatial dependence (DSD ≤ 25%), moderate spatial dependence (25% <DSD ≤ 75%) and strong spatial

dependence (DSD> 75%) (ZIMBACK, 2001). According to Cavalcante et al. (2011), when strong and moderate DSD classes are found, it means that the distribution of variables in space does not happen randomly. Models were selected based on the lowest Sum of Squares of Residues (SQR) and best $R^2$ (coefficient of spatial determination). The coefficient of determination ($R^2$) values inform about the fit quality of the semivariogram model.

### Spatial distribution analysis of soil physical attributes

Based on the models obtained for the adjusted semivariograms, the spatial distribution of clay, sand, silt, DS and SCS, litter, respectively at the depths of 0-10 and 10-20 cm were analyzed by the geostatistical ordinary kriging interpolation method (LANDIM, 2006).

The clay, sand and silt fractions tend to be related to soil density so that sandy soil may have higher density than clay, whereas silt soil tends to have an intermediate behavior (LIBARDI, 2005). Pereira *et al*. (2016) state that for clay soils the critical BD is between 1.30 and 1.40 g $cm^{-3}$, and between 1.40 and 1.50 g $cm^{-3}$ and from 1.70 to 1.80 g $cm^{-3}$ for medium-textured and sandy textured soils, respectively.

Map 1 was used to evaluate spatial distribution of the attributes clay, sand, silt and soil density, respectively at depths of 0-10 and 10-20 cm. Map 2 was used to assess soil carbon stock at both depths. Map 3 for spatial distribution of the litter was used to analyze the impacts of vegetation cover through the use systems, such as brachiaria pasture, native forest, orchard and andropogon pasture.

Finally, the spatial distribution maps of the particle size fractions, BD, SCS, were compared by means of biostatistics with the litter map in search of evidence of a relationship between them. The litter is a precursor of soil organic matter so that it can influence attributes such as density and carbon stock itself.

The Surfer v. 8.0 (GOLDEN SOFTWARE, 2002) software was used for manipulation and visualization of the spatial distribution by constructing the isoline maps of the variables, according to the geographical coordinates. In order to verify the presence of anisotropy (gradual variations toward one direction and rapid or irregular variations in the other), four-way semivariograms were calculated at 45° intervals (0, 45, 90 and 135°). In neither case was anisotropy evidenced in the data set. Therefore, semivariograms with 90º isotropic were assumed.

Data and map analyses were performed by treating the surveyed area as a whole, without dividing into paddocks. The division displayed on the map is for orientation and distinction of types of land use.

## RESULTS AND DISCUSSION

### Descriptive analysis and semivariograms

The results for the descriptive analysis for values of clay, sand, silt, Bulk Density (BD), litter and Soil Carbon Stock (SCS) at both depths are shown in Table 1.

The Shapiro & Wilk (SW) (1965) test stated the normality of the data at both depths for all variables. The values found for the asymmetry ($C_s$) and kurtosis ($C_k$) coefficients, mean and median reinforce the result found in the SW test.

Analysis of $C_s$ and $C_k$ associated with standard error at both depths shows that most variables, except clay (0-10 and 10-20 cm), silt and SCS (10-20 cm), tend to have approximate symmetrical and normal distributions. Clay (0-10 and 10-20 cm), silt and SCS (10-20 cm) variables presented asymmetric behavior, according to the thresholds proposed by Webster (2001). However, both the mean and median values of the same and other variables are close to each other, and reinforce the idea that the data distribution tends to symmetry and meets normality conditions, as it was observed in the SW test. Such finding shows that the evaluated variables are not dominated by atypical distribution values and are suitable for the use of geostatistics (CAMBARDELLA *et al*., 1994).

The coefficients of variation (CVs) were divergent, ranging from low, medium and high at both depths. High CV values were found for litter (90% at 0-10 cm) and silt (63% at 10-20 cm), which indicate that the values of the series dispersed in relation to the mean.

The high CV value observed for litter may be related to the different constant land uses in the area (brachiaria pasture, andropogon pasture, orchard and native forest). This diversity of environment conditions the difference in the amount of existing plant material on the soil, which results in a heterogeneous environment for the litter.

The adjustment parameters of semivariograms representing the 0-10 and 10-20 cm depth layer are shown in Table 2.

**Table 1.** Descriptive analysis of physical attributes, litter and soil carbon stock (SCS) at 0-10 and 10-20 cm depths, respectively.

| Attribute | Mean | Median | Mode | Values | | Coefficient | | | SW |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Min | Max | Var. (%) | $C_s$[1] | $C_k$[2] | |
| | | | | 0-10 cm | | | | | |
| Clay | 115.78 | 108.1 | 102.3 | 23.2 | 288.9 | 34 | 0.90 | 2.10 | 0.96 ** |
| Sand | 779.71 | 777.5 | 750 | 545.5 | 905 | 7 | -0.39 | 0.97 | 0.97 ** |
| Silt | 104.51 | 97.4 | 153.4 | 2.3 | 208.8 | 46 | -0.07 | -0.88 | 0.97 ** |
| BD | 1.65 | 1.67 | 1.64 | 1.15 | 1.94 | 11 | -0.54 | -0.30 | 0.96 ** |
| Litter[3] | 62.64 | 59.9 | 0 | 0 | 266.09 | 90 | 0.66 | -0.17 | 0.91 ** |
| SCS | 53.39 | 51.32 | 34.34 | 20.65 | 104.59 | 31 | 0.50 | -0.37 | 0.92 ** |
| | | | | 10-20 cm | | | | | |
| Clay | 150.83 | 143.4 | 194.2 | 67.1 | 321.2 | 32 | 0.87 | 0.94 | 0.95 ** |
| Sand | 777.03 | 786 | 750 | 623.5 | 876 | 7 | -0.41 | -0.38 | 0.97 ** |
| Silt | 72.14 | 64.1 | 67.4 | 5.8 | 193.3 | 63 | 0.70 | -0.33 | 0,94 ** |
| BD | 1.65 | 1.64 | 1.67 | 1.23 | 2.08 | 13 | -0.03 | -0.71 | 0.98 * |
| SCS | 48.61 | 45.67 | 37 | 26.8 | 85.82 | 29 | 0.85 | 0.01 | 0.98 ** |

Min: Minimum; Max: Maximum; $C_s$: Asymmetry coefficient (1) standard error associated with $C_s$ = 0.19; $C_k$: Kurtosis coefficient (2) standard error associated with $C_k$ = 0.38; SW: Shapiro & Wilk (normality test);**; * significant at 1 and 5% respectively by the SW test; Clay, Sand and Silt (g $kg^{-1}$); BD: Bulk density (g $cm^{-3}$); Litter (g) (3) amount in 0.25 x 0.25 m area; SCS: Soil Carbon Stock (t $ha^{-1}$).

**Table 2.** Models and estimated parameters of semivariograms adjusted to the values of the variables evaluated at 0-10 and 10-20 cm depths, respectively.

| Attribute | Parameter | | | | | | |
|---|---|---|---|---|---|---|---|
| | Model | $C_0$[1] | $C_0$+C[2] | SDD (%)[3] | Class | A[4] (m) | $R^2$* |
| | | | | 0-10 cm | | | |
| clay | expon | 1 | 1910 | 99.9 | Strong | 48 | 0.920 |
| sand | expon | 1 | 2977 | 100 | Strong | 31 | 0.847 |
| Silt | expon | 1 | 2791 | 100 | Strong | 50 | 0.970 |
| BD | expon | 0.0108 | 0.035 | 69.2 | moderate | 121 | 0.753 |
| Litter[5] | gauss | 1 | 2965 | 100 | Strong | 48 | 0.888 |
| SCS | expon | 5.7 | 261.1 | 97.8 | strong | 14 | 0.588 |
| | | | | 10-20 cm | | | |
| clay | expon | 1 | 2858 | 100 | strong | 34 | 0.816 |
| sand | expon | 1 | 2873 | 100 | strong | 37 | 0.907 |
| Silt | spherical | 158 | 2146 | 92.6 | strong | 15370 | 0.749 |
| BD | expon | 0.00005 | 0.0249 | 99.8 | strong | 20 | 0.461 |
| SCS | linear | 157.73 | 200.25 | 21.2 | weak | 232 | 0.136 |

(1)$C_0$: Nugget effect; (2)$C_0$+C: Plateau; (3)SDD: Spatial dependence degree (4)A: Range; (*)$R^2$: Coefficient of determination; Clay, Sand and Silt (g $kg^{-1}$); BD: Bulk density (g $cm^{-3}$); Litter (g) (5) amount of litter in an 0.25 x 0.25-m area; SCS: Soil Carbon Stock (t $ha^{-1}$).

Range values ranged from 14 to 121 m at a depth of 0-10 cm for SCS and from 20 to 232 m at a depth of 10-20 cm for BD, which correspond to the radii of areas considered homogeneous (LIMA et al., 2014).

The sand, silt and clay fractions showed low range values at both depths, except for silt in 10-20 cm depth with 153.70 m of spatial correlation. The result shows continuous variation of the particle size fractions, which probably begins within each subarea and extends from one use to the other. The spatial discontinuity evidenced in the range values for them can be attributed to characteristics of the source material itself and pedogenic factors and processes acting on the studied soil, since particle size fractions are little influenced by management and agricultural practices (SILVA *et al*., 2010).

On the other hand, the high range value found for BD (121 m) on surface (0-10 cm) shows its tendency to spatial continuity, but with a moderate degree of dependence. This is probably due to fluctuations in BD values in specific areas of the study area due to the variation of gravel content over the area. It is also observed that the range value has been drastically reduced in subsurface (20 m to 10-20 cm depth), but now with strong spatial dependence. Corroborating this work, Carvalho et al. (2013) observed a reduction in the BD range value at depth (294.78 m at 0-10 cm and 39.27 at 10-20 cm).

The low range value (48 m) observed for the litter variable predicts a continuous variation that starts within each land use subarea and intensifies between uses, so that a gradual variation occurs between these environments.

The SCS showed low surface range (14 m at 0-10 cm) and high subsurface range (232 m at 10-20 cm). However, the latter is accompanied by weak spatial dependence, which predicts a nugget effect dominating structured variability. The low surface range observed, together with the low subsurface spatial dependence, may be the result of abrupt variations in the SCS resulting from quantified discrepant values in area-specific zones. The natural variations that occur in the process of accumulation of Organic Carbon (CO), along with the oscillations in the values of BD may have contributed to the result, since they are considered in the calculation of the SCS.

The relations between nugget effect ($C_0$) and plateau ($C_0$ +C) showed a predominance of strong Spatial Dependence Degree (SDD) at both depths, except for BD at 0-10 cm and SCS at 10-20 cm. According to the classification proposed by Zimback (2001), the BD and SCS variables presented moderate and weak SDD, respectively. This can be attributed to the discrepant oscillations in the values of these variables, as previously mentioned, which result in the weakening of the spatial dependence between the points.

The finding of spatial dependence for all variables at both depths demonstrates that the sampling distance was sufficient to display the full variance of the data.

Most variables presented a $C_0$ of less than 10% in surface and subsurface, except for BD (0-10 cm) and SCS (10-20 cm). Thus, the result shows that over 90% of their variation is explained by the spatial dependence observed on SDD values greater than 75%, although there is not necessarily dependence on the type of land use, except for litter and SCS. The high $C_0$ value found for SCS (78.8%) indicates that only a small portion of the variability observed for this variable has spatial dependence.

Most variables fit the exponential and spherical model at both depths, in agreement with Neves Neto *et al*. (2013), who indicated such models as the most common to soil attributes that is verified due to $R^2$ values close to 1 for most variables at both depths, except for SCS at 0-10 cm and BD and SCS at 10-20 cm, so the semivariogram models represent the data set well.

**Spatial distribution of the soil physical attributes and litter**

The spatial distribution values for sand, silt and clay indicate that the soil textural class varies from medium to sandy in both native forest subarea and cropping systems at both depths (Figure 2). Lima *et al*. (2013) in a study of soil physical attributes under different uses found results similar to those in this work. These authors observed that the three land use systems (native field, corn crop with fallow or rest interval and brachiaria pasture) did not promote any changes in the textural classes of the soil under study.

The visualization of the spatial distribution maps of the granulometric fractions allows us to observe that the values, as well as their spatial distribution along the area, have little or no relation to the different land uses (brachiaria pasture, andropogon pasture, orchard and native forest pastures) at both depths (Figure 2 a, b, c, d, e, f). The spatial discontinuity shown in the range values for sand, clay and silt, the latter only at 0-10 cm and can be seen on the maps. As no concentrations were observed for any of the fractions in specific uses, the authors conclude that the spatial discontinuity

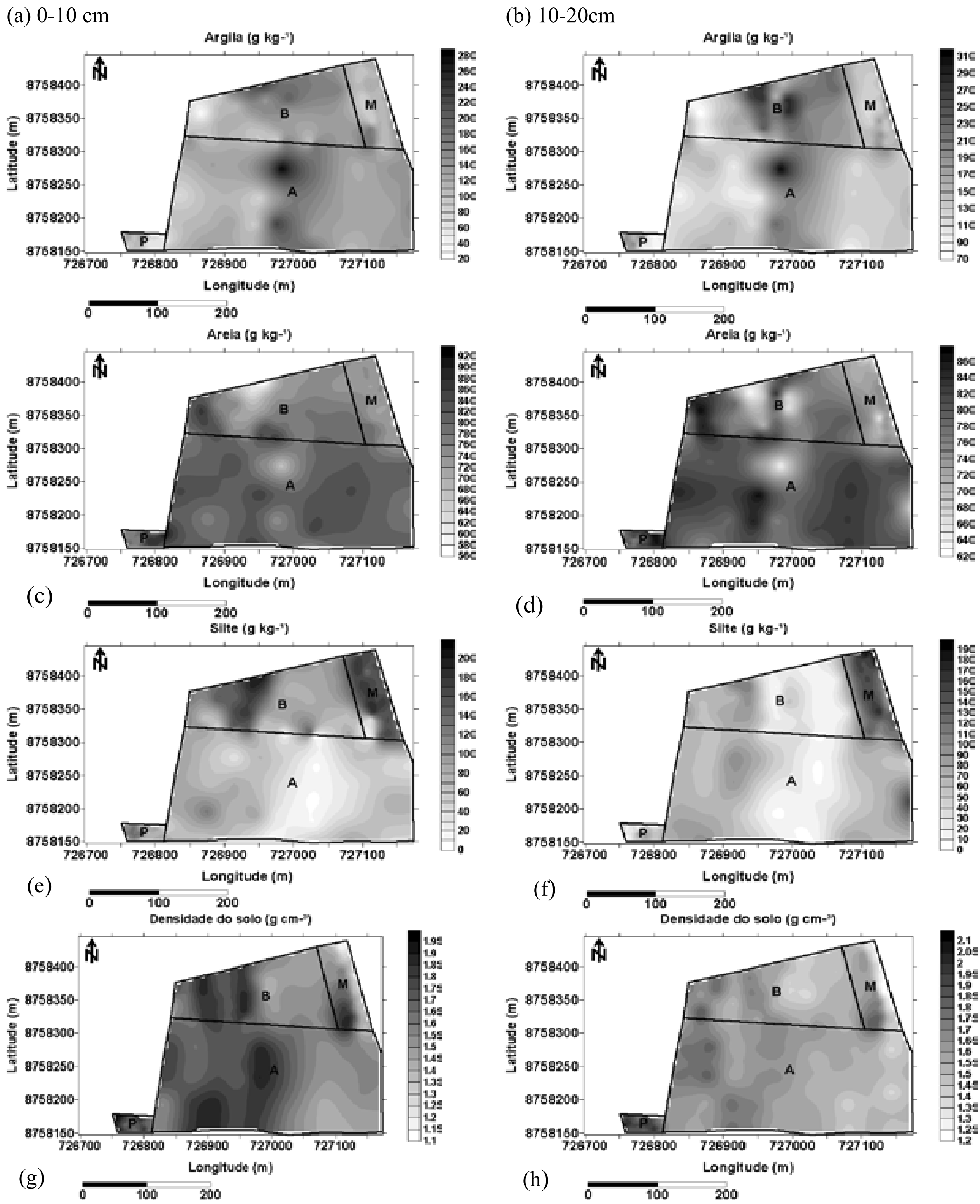


**Figure 2.** Spatial distribution map of the attributes clay (a and b), sand (c and d), silt (e and f) and bulk density (g and h), respectively at the depths of 0-10 and 10-20 cm, in the brachiaria pasture areas (B ), native forest (M), orchard (P) and andropogon pasture (A).

for these variables is related to the soil constituent material rather than to its use.

When considering the classification cited by Pereira *et al*. (2016), some points of the brachiaria, orchard and andropogon subareas showed greater BD values than those considered critical and indicative of compaction, both at 0-10 and 10-20 cm depth (Figure 2 g, h). However, when analyzing the quantified values in the native forest subarea, BD values were also higher than those considered critical at both depths. Thus, it is understood that the high values of BD may be associated with the significant amount of gravel found in the area, since the control subarea also showed zones with high values for BD. As the texture of the area varies from medium to gravelly sandy, the amount of gravel directly interferes with the weight of soil mass, and according to Reinert and Reichert (2017), any factor that interferes with soil mass-volume relations affects BD. Therefore, it cannot be said that the area indicates a compaction process.

Bulk density spatial distribution maps show dramatic variations in specialization, which may have resulted in moderate spatial dependence (Figure 2 g, h). It was also observed increase in its values in depth. According to Bicalho (2011), BD tends to increase in depth due to several factors, among which the lower aggregation, reduced organic matter content and decreased soil porosity stand out.

The spatial distribution of soil carbon stock (SCS) was influenced by management systems (Figure 3). It was found that the native forest subarea presents natural variation in the SCS, which extends to the orchard, andropogon and bracharia subareas at both depths (Figures 3a and 3b). However, the conversion of native forest subarea to cultivation systems reduced the SCS in specific areas, especially pastures. These reductions may be related to low OC accumulation or losses. In the orchard, the recently cropped sites probably return few plant residues and low amounts of cattle manure to the soil, which are the main contributors to OC accumulation in the subarea. In pastures, low OC accumulation can be attributed to low fertility, reflected in their poor cover. According to Assad *et al*. (2013) soil fertility plays a fundamental role in the accumulation of OC in pastures, that is, the accumulation of organic material depends on the aerial biomass production, which is a result of the soil fertility status of the managed pastures. Baldotto *et al*. (2015) evaluated the SCS under different management systems in the Paraopeba river basin and studies have shown that the increase in SCS is related to the increase of soil fertility.

The points with higher SCS at 0-10 and 10-20 cm depths overlapped with the highest clay and lowest sand contents. This shows that in sandy areas, the soil OC loss was higher, which can be attributed to the potential that sandy soil have to lose OC (LAL *et al*., 2007). This fact is explained by the higher leaching, low clay activity and lower soil particle aggregation (OLIVEIRA *et al*., 2015). In addition, clay has been identified as a determinant in the stabilization of soil organic matter, and SCS have a direct relationship with it (ADUAN, 2003).

The spatial distribution map of the litter shows that the quantified values for it varied according to the type of vegetation cover (Figure 4). The spatial discontinuity shown in the range value for this variable is likely to be mostly due to the andropogon subarea, since it was in this subarea that the highest values and the most accentuated spatial variability were concentrated.

(a) 0-10 cm (b) 10-20cm

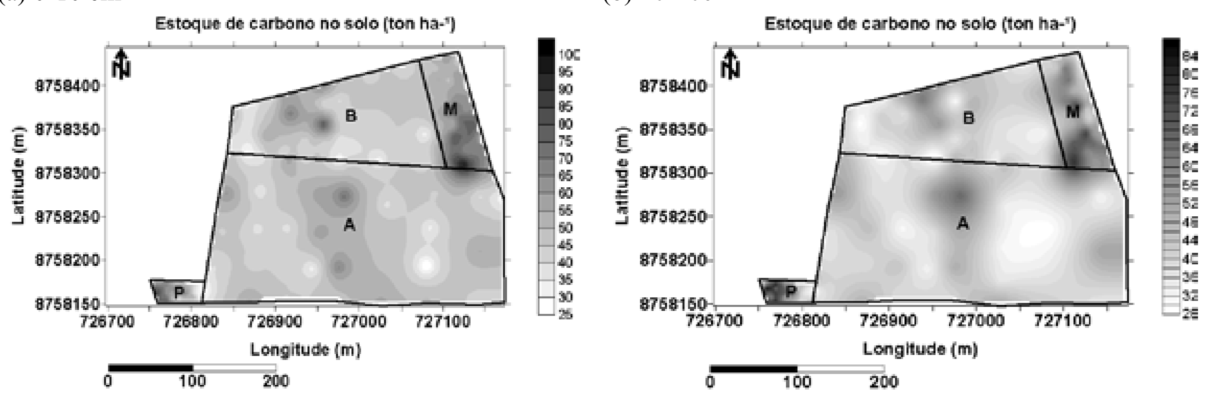


**Figure 3**. Spatial distribution map of soil carbon stock at 0-10 cm (a) and 10-20 cm (b) depths in brachiaria pasture (B), native forest (M), orchard (P) and pasture areas of andropogon (A).

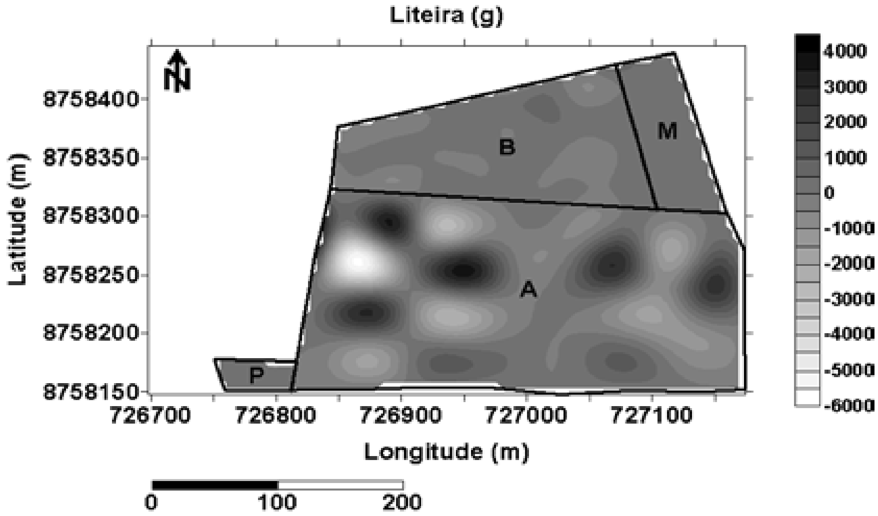


**Figure 4**. Map of the spatial distribution of the litter in the areas of brachiaria pasture (B), native forest (M), orchard (P) and andropogon (A) pasture.

The comparison through the biostatistics of the spatial distribution maps of the particle size and BD fractions (Figure 2) and the SCS (Figure 3) with the litter map showed that there was no relationship between them. The variations shown for litter within the subareas of land use, particularly in the pastures may be related to the nutrient contents of the soil as a function of the accumulation organic matter, which reflects in larger plant biomass and consequently larger litter. The variation between environments can be attributed to the sampling season (July and August), which coincided with high temperatures and low soil moisture, characteristics of the region under study. Grasses reach the stage of senescence faster under such conditions than medium and large species, such as those found in forest and orchard areas. The root system of the latter is characterized by the presence of long pivoting root capable of a considerable deepening in the soil, and by the expressive volume of vertical roots, so that they achieve greater area of exploitation of water and nutrients of the soil and thus slow down the process of senescence, reflecting in a lower amount of litter when compared to grasses.

## CONCLUSIONS

- The different land uses through orchard, brachiaria, andropogon and native wood caused spatial variability in physical attributes, litter and soil carbon stock;
- The orchard, brachiaria and andropogon did not promote any changes in sand, silt, clay and BD at any depth. On the other hand, litter and SCS were influenced by the different uses;
- The spatial distribution of soil carbon stock (SCS) was influenced by management systems. The conversion of the native forest subarea to cultivation systems reduced the SCS in specific areas, especially in pastures, both in surface (0-10 cm) and subsurface (10-20 cm);
- The orchard subarea has emerged as the most promising system in carbon accumulation due to the presence of cattle manure, since the SCS have matched those of native forest in areas where vegetation is established for 14 years;
- Values of SCS were lower than native forest only at newly implanted sites. It was also observed that the SCS values decreased according to the depth, which can be attributed to non-tillage in the soil.
- The study may further assist in efficient soil management through varying rate practices.

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