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Spatial variability of organic carbon and soil carbon stock in pasture areas in União Bandeirantes, Rondônia

Raquel Manhuary de Araújo[1], Douglas Marcelo Pinheiro da Silva[2], Milton César Costa Campos[3], Alan Ferreira Leite de Lima[4], Wildson Benedito Mendes Brito[5], Luís Antônio Coutrim dos Santos[6], José Maurício da Cunha[7]

[1]Graduanda em Agronomia, Instituto de Educação Agricultura e Ambiente, Universidade Federal do Amazonas, Rua Circular Municipal, 786, CEP 69800-000, Humaitá, Amazonas. quel.araujo4320@gmail.com.
[2]Doutor em Horticultura, Docente do Instituto de Educação, Agricultura e Ambiente, Universidade Federal do Amazonas, Rua Circular Municipal, 786, CEP 69800-000, Humaitá, Amazonas. dougllasmarcelo@gmail.com.
[3]Doutor em Ciência do Solo, Docente do Centro de Ciências Agrárias, Universidade Federal da Paraíba, 12 Rodovia, PB-079, CEP 58397-000, Areia, Paraíba, Brasil. mcesarsolos@gmail.com.
[4]Doutorando em Agronomia Tropical, Faculdade de Ciências Agrarias, Universidade Federal do Amazonas, Av. General Rodrigo Octavio, 1200, CEP 69067-00, Manaus, Amazonas.ala_leite@hotmail.com (autor correspondente).
[5]Doutorando em Agronomia Tropical, Faculdade de Ciências Agrarias, Universidade Federal do Amazonas, Av. General Rodrigo Octavio, 1200, CEP 69067-00, Manaus, Amazonas. wild.brito@gmail.com.
[6]Doutor em ciência do solo, Docente do Centro de Estudos Superiores de Itacoatiara, Universidade do Estado do Amazonas, Av. Mário Andreazza, 2960, CEP 69101-603, Itacoatiara, Amazonas. santoslac@gmail.com.
[7]Doutor em Física Ambiental, Docente do Instituto de Educação, Agricultura e Ambiente, Universidade Federal do Amazonas, Rua Circular Municipal, 786, CEP 69800-000, Humaitá, Amazonas. maujmc@gmail.com.

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A B S T R A C T

In the Amazon region, it is common the conversion of natural environments for the cultivation of pastures using fire. This management releases a large part of the organic carbon present in the soil to the atmosphere, mainly affecting the attributes of the soil. The objective of this work was to evaluate the spatial variability of organic carbon and carbon stock in areas in União Bandeirantes, RO state. In the field, three areas were selected: brachiaria (Brachiaria brizantha) and mombaça (Panicum maximum) and forest, where sampling grids were demarcated with regular spacing of 10 x 10 m, with 70 sampling points being collected in the pasture areas and 60 in the forest area, at depths of 0.00-0.10 m and 0.10-0.20 m. In the laboratory, determined: soil density, organic carbon and estimated carbon stock were. Along with the data obtained, descriptive statistics, average test, Kolmogorov-Smirnov normality test and geostatistical analysis were performed. All soil attributes showed spatial dependence in all areas, with some attributes showing greater variability. Through the kriging maps, it was possible to spatially relate the attributes, visualize the spatial distribution and verify management zones for the areas.

Keywords: spatial distribution, Amazon rain forest, organic matter.

Variabilidade espacial do carbono orgânico e do estoque de carbono do solo em áreas de pastagem em União Bandeirantes, Rondônia

RESUMO

Na região amazônica é comum a conversão de ambientes naturais para o cultivo de pastagens com o uso do fogo. Esse manejo libera grande parte do carbono orgânico presente no solo para a atmosfera, afetando principalmente os atributos do solo. O objetivo deste trabalho foi avaliar a variabilidade espacial do carbono orgânico e do estoque de carbono em áreas de União Bandeirantes, RO. No campo, foram selecionadas três áreas: braquiária (*Brachiaria brizantha*) e mombaça (*Panicum maximum*) e mata, onde foram demarcadas grades amostrais com espaçamento regular de 10 x 10 m, sendo coletados 70 pontos amostrais nas áreas de pastagem e 60 nas a área de mata, nas profundidades de 0,00-0,10 m e 0,10-0,20 m. Em laboratório, determinou-se: densidade do solo, carbono orgânico e estoque de carbono estimado. Juntamente com os dados obtidos, foram realizadas estatísticas descritivas, teste de média, teste de normalidade Kolmogorov-Smirnov e análise geoestatística. Todos os atributos do solo apresentaram dependência espacial em todas as áreas, com alguns atributos apresentando maior variabilidade. Através dos mapas de krigagem foi possível relacionar espacialmente os atributos, visualizar a distribuição espacial e verificar as zonas de manejo das áreas.

Palavras-chave: distribuição espacial, floresta amazônica, matéria orgânica

Introduction

Soil organic carbon represents 58% of soil organic matter, which is a mixture of partially decomposed plant, animal and microbial material (Stockmann et al., 2013). In pasture, more than 90% of the C stock is stored in the soil (Reeder and Schuman, 2002). However, it takes longer to build up soil organic carbon than it does to lose it (Smith, 2014), which underscores the importance of conserving this ecosystem service to help keep CO2 out of the atmosphere and the many benefits it attributes to it in the chemical, physical and biological attributes of the soil (Cassol et al., 2019; Gerke, 2022).

Considering environmental and economic purposes, currently, a great emphasis has been given to the Amazon in terms of carbon stocks contained in its ecosystems as potential precursors of increases in atmospheric CO_2 concentrations (Fonseca et al., 2018). Determining soil carbon stocks, as well as the soil attributes that interfere with this stock, are extremely important to determine management practices that maintain carbon in the terrestrial environment and appropriate ways of conserving the environment (Silva et al., 2019). The harmony of these attributes can be altered by the use and management of the soil, being beneficial or harmful to the health of the soil (Silva et al., 2017).

Changes in tropical natural ecosystems can cause reductions in carbon inputs, which change according to use, management adopted, physical, chemical and biological attributes (Santos et al., 2017). The soil maintained under natural conditions, under native vegetation, has physical characteristics suitable for the ideal development of plants (Cunha et al., 2017). However, when native ecosystems are altered, the dynamic balance is disrupted and generally causes lower carbon inputs than outputs, leading to a reduction in the quantity and change in the quality of the soil organic matter (Enck et al., 2022).

One of the great uses of the land in the region and that generate a huge contribution to the local GDP is through livestock, and consequently the implementation of a pasture system. In pasture systems, when properly managed, they can improve many soil properties, such as water retention, aggregate stability, soil organic matter and nutrient cycling (Franzluebbers et al., 2011). Braz et al. (2013), observed an increase in carbon stocks in pastures after 8 years of use in relation to the forest, and that, if fire is frequently used for cleaning, a decrease occurs.

These modifications, in addition to changing in quantity, also change spatially, modifying their distribution in the environment (Nogueira et al., 2020). Thus, knowledge of the variability and spatialization of carbon in the soil is essential for the characterization and monitoring of a given area in relation to its use and management, and, therefore, the possible impacts that it may be causing (Oliveira, et al., 2015). Among the tools for studying spatial distribution, geostatistics stands out, in which through kriging it is possible to generate maps of area use where risk areas can be identified and then carry out conservation management, becoming an important tool for use in agriculture, and at the same time of environmental value, when considering the soil quality (Soares et al., 2018; Linhares et al., 2016).

Bearing in mind the importance of pastures used for agriculture and the changes that it can cause to the dynamics of carbon in the soil, it is necessary to carry out studies that evaluate the concentration, behavior and spatial distribution of carbon, as well as its stock in the soil in an environment of pasture use in the Amazon region.

Methodology

Characterization of the study area

The study was carried out in the União Bandeirantes district located in the municipality of Porto Velho, Rondônia, Brazil, in three areas, two areas under different uses with cultivation of Brachiaria (*Brachiaria brizantha*) and Mombaça (*Panicum maximum*), and an area of native forest (Figure 1).

The climate of the region, according to the Köppen classification, belongs to group A (Rainy Tropical Climate) and climate type Am (monsoon-type rains), with a short dry season between the months of June and September. The annual rainfall varies from 2,500 to 2,800 mm. The annual temperature is between 24 and 26 °C. The relative humidity is quite high, varying between 85% and 90% in the rainy season and between 60 and 70% in the dry season. The local relief is gently undulating with altitudes ranging from 100 to 200 m (Alvares et al., 2013).

The study area is located on the boards of the Amazon depression, the regional relief, has a smooth undulating surface, with altitude ranging from 100 to 200 m. The soils found are developed from undifferentiated sedimentary covers, associated with environments of alluvial fans, river channels, floodplains and lakes, consisting of sediments with granulometry that varies from gravel to clay, with significant lateritization

(Adamy, 2010). Soils for different uses have local relief ranging from flat to gently undulating and well drained. They are classified as typical Dystrophic Yellow Latosol, A moderate, clayey texture according to the Brazilian Soil Classification System (Santos et al., 2018). The soil characterization for physical and chemical attributes are presented in Table 1, while the history of the area is presented in Table 2.

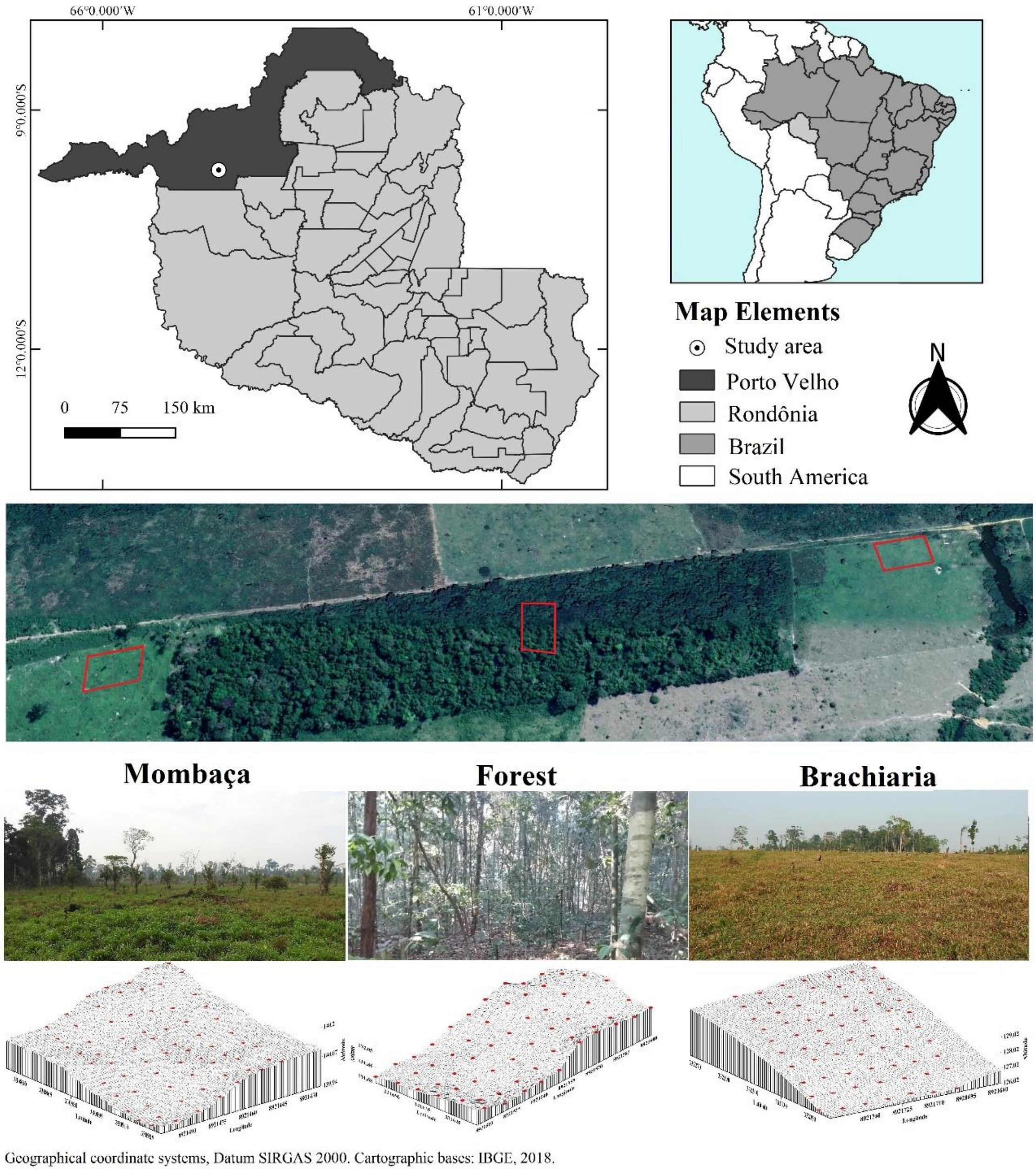

Figure 1. Location map of the study areas in União Bandeirantes, Porto Velho, RO state.

Table 1. Physical and chemical characterization of soils with brachiaria, mombaça and forest, at depths of 0.00-0.10 and 0.10-0.20 m, in the municipality of Porto Velho, Rondônia state, Brazil, 2019

Variables	pH	Al^{3+}	H+Al	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	CTC	V	P
	H_2O	---------------------- $cmol_c.kg^{-1}$ ----------------------							%	$mg.kg^{-1}$
Forest										
0.00-0.10 m	3.73	1.77	7.84	0.61	0.10	0.09	0.004	8.61	8.65	5.52
0.10-0.20 m	3.53	1.93	6.44	0.50	0.05	0.05	0.005	7.13	8.37	3.39
Brachiaria										
0.00-0.10 m	4.67	0.62	8.16	1.30	0.26	0.07	0.011	14.69	33.54	4.38
0.10-0.20 m	5.03	0.88	5.22	0.42	0.06	0.02	0.006	5.75	8.89	2.15

Mombaça										
0.00-0.10 m	4.88	0.63	5.15	0.88	0.45	0.11	0.011	21.18	33.01	3.53
0.10-0.20 m	4.48	0.94	4.55	0.44	0.28	0.03	0.002	5.30	13.95	1.81

Variables	Sand	Silt	Clay	DMG	DMP	Ug	Pt	MiP	MaP	RSP
	------ $g.kg^{-1}$ ------			mm		$kg.kg^{-1}$	------ $m^3.m^{-3}$ -----			MPa
Forest										
0.00-0.10 m	544	57	399	2.99	3.19	0.26	0.51	0.30	0.21	1.05
0.10-0.20 m	476	66	458	2.48	2.89	0.25	0.45	0.35	0.10	2.05
Brachiaria										
0.00-0.10 m	693	28	279	2.75	3.11	0.20	0.43	0.28	0.16	1.71
0.10-0.20 m	643	37	320	2.22	2.67	0.19	0.40	0.29	0.11	1.86
Mombaça										
0.00-0.10 m	603	43	354	2.95	3.19	0.23	0.47	0.30	0.16	1.76
0.10-0.20 m	522	52	426	2.32	2.73	0.22	0.43	0.32	0.12	1.72

CTC: capacity to exchange cations; V: base saturation; DMG: geometric mean diameter; DMP: weighted average diameter; Ug: gravimetric humidity; Pt: total porosity; MiP: microporosity; MaP: macroporosity; RSP: soil penetration resistance.

Table 2. Description of use and history of areas under forest and pasture in União Bandeirantes, Porto Velho, RO state

Use of the soil	Usage history
Brachiaria (*Brachiaria decumbens*)	Area resulting from felling and burning of the forest, with manual stump cleaning to clean the area in the first year of cultivation. There was never any fertilization and liming in the cultivated areas, it has 26.36 ha, was implemented in 2008, was unused for a year and was used infrequently until 2010, after which 4.5 animals per hectare were used in the 45-day rotation with mombaça.
Mombaça (*Panicum maximum)*	Area resulting from felling and burning of the forest, with manual stump cleaning to clean the area in the first year of cultivation. There was never any fertilization and liming in the cultivated areas, it has 17.92 ha, was introduced in 2007, was unused for three years, after which 6.14 animals per hectare were used in the 45-day rotation with brachiaria.
Forest	Characterized as a dense tropical rainforest, its vegetation is evergreen, consisting of dense and multistratified trees between 20 and 50 meters in height (Perigolo et al., 2017).

Field methodology

For each pasture area, Brachiaria and Mombaça, a mesh of 60 x 90 m was established, and in the native forest area, a mesh of 90 x 50 m with regular spacing of 10 m between the sampling points for each area. Soils were sampled at the crossing points of the meshes, at depths of 0.00-0.10 and 0.10-0.20 m, making a total of 70 collection points in each pasture area and 60 points in the area of forest, totaling 400 soil samples in all. The samples with preserved structure were collected in each area. These samples were used to determine total organic carbon (TOC) and carbon stock (EST. C). The soil density (Ds) was determined from undisturbed samples using volumetric rings collected in the horizons, obtained by the ratio of the soil mass dried in an oven at 105 °C and the ring volume (Teixeira et al., 2017).

Total organic carbon was determined by the Walkley-Black method, modified by Yeomans & Bremner (1988). In the wet method, soil organic matter was oxidized with a potassium dichromate mixture. It was placed on the hot plate until it reached boiling point, after reaching boiling point, it was removed and allowed to cool. In the already cold solution, 80 mL of distilled water was added, followed by 2 mL of o-phosphoric acid (1 mol) and 3 drops of diphenylamine (1%), the titration was carried out with ammoniacal iron sulfate (0.05 mol/l) (Walkley & Black, 1934; Yeomans & Bremner, 1988).

The determination of TOC occurs indirectly as a function of the reaction of carbon present in organic compounds with potassium dichromate. The calculation of the TOC content was performed by the volume of potassium dichromate used in the oxidation of organic matter, which was obtained by the difference between the volume of a blank test and the sample by titration with ammoniacal ferrous sulfate solution (Teixeira, et al., 2017).

The carbon stock was calculated by the equation:
(1)
EST.C = (Ds .h .TOC)/10

Where:

EST. C - carbon stock (t ha^{-1});
Ds - soil density (g cm^{-3});
h - thickness of the sampled soil layer (cm);
TOC - total organic carbon (g kg^{-1}).

Statistical and geostatistical analysis

The data statistics were evaluated using descriptive statistics where the mean, median, coefficient of variation, asymmetry coefficient and kurtosis were calculated. Comparisons of means of variables within each environment studied were analyzed by the Tukey's test at 5% probability. The hypotheses of data normality within each environment were tested using the Kolmogorov-Smirnov (KS) test. The data were submitted to statistical analysis by statistical software Statistica 7 (Statsoft, 2004).

Geostatistics was used to assess the spatial variability of organic carbon and carbon stock. In order to perform the geostatistical analysis, it was necessary to know if there is spatial dependence or not of the attributes studied, where it was verified through the semivariogram graph. Based on the stationarity assumption of the intrinsic hypothesis, which the semivariogram was estimated by:

$$(2) \qquad \hat{y}(h)=\frac{1}{2\eta(h)}\sum_{i=1}^{\eta(h)}[Z(x_i) - Z(x_i+h)]^2$$

Where:
$\hat{y}(h)$ - semivariance value for a distance h;
$\eta(h)$ - number of pairs involved in the semivariance calculation;
Z(xi) - value of the attribute Z in the position xi;
Z(xi+h) - Z attribute value separated by a distance h from the position xi.

The semivariograms were adjusted based on the best coefficient of determination (R2) and cross-validation (VC), estimated by the GS+ 7.0 Software (Gamma Design, 2004). Based on these adjustments, the coefficients of the theoretical model for the semivariogram were defined: nugget effect (C0) = semivariance value for distance zero, which represents the component of random variation; structural variance (C1); threshold (C0 + C1) = semivariance value in which the curve stabilizes over a constant value; and range (a) = distance from the origin to where the plateau reaches stable values, expressing the distance beyond which the samples are not correlated (Trangmar et al., 1985).

For the analysis of the degree of spatial dependence (GDE) of the attributes under study, the classification of Cambardella et al. (1994), in which soil properties are considered to have strong spatial dependence if the nugget effect ratio (C0) in relation to the plateau (C0+C1) is less than 25%. If the ratio is between 26 to 75%, spatial dependence is considered moderate, while if the soil property is greater than 75% to approximately 95%, they are classified as weak spatial dependence.

After adjusting the permissible mathematical models, the data were interpolated through kriging in the Surfer software version 15.0. The construction of Kriging maps made it possible to verify and spatially relate the organic carbon and carbon stock in the forest and pasture area of União Bandeirantes – RO state.

Results and discussion

The results of the descriptive analysis for the studied soil attributes of the areas of native forest, Brachiaria and Mombaça at depths of 0.00-0.10m and 0.10-0.20 m are represented in Table 3, in addition to the results of the Tukey test. As a function of the coefficient of variation (CV%), the variability of the attributes can be classified as low, medium and high variation, according to the classification by Warrik & Nielsen (1980). It is observed that most of the CV% values for the two studied depths presented medium variation (12%-60%), with the exception of density (Ds) in the three areas, which presented low variation (CV<12%). The mean has meaning and the series is homogeneous, when a coefficient is less than 35%, it can be used as a representative of the series from which it was acquired. If it is greater than 35%, the series is heterogeneous and the mean does not have much meaning, and the series is very heterogeneous and the mean has no meaning when it is greater than 65% (Nogueira, 2007).

According to the results of the Kolmogorov-Smirnov normality test, we can say that all data are normal for all attributes in all areas studied, at the level of 5% probability (Table 3).

For Ds, a statistical difference was observed between all the areas studied at the two evaluated depths. The brachiaria area at both depths has the highest average with 1.39 and 1.51 $kg.dm^{-3}$ respectively, followed by the mombaça area (1.32 and 1.45 $kg.dm^{-3}$) and then the forest area that presented the lowest average (1.16 and 1.40 kg.dm^{-3}) at the two depths evaluated respectively, which can probably be explained by the high density of plants and the accumulation of litter on the soil surface (Mascarenhas et al., 2017). Despite this, the values of Ds in the studied areas are below the critical limit (1.75 kg.dm^{-3}) (Neves Junior et al., 2013). These higher values of Ds in pasture areas are due to the compaction caused by the trampling of large animals. Torres et al. (2014) observed that this increase in soil density depends on the intensity of trampling, moisture and soil type.

The TOC in the forest area showed higher levels at both depths, with averages of 23.88 and 18.09 g.kg^{-1} respectively, differing from the other areas. The areas of Brachiaria and Mombaça did not show statistical differences between them in the depth of 0.00-0.10 m. At a depth of 0.10-0.20 m, the areas with pasture differed from each other, with Brachiaria being the area with the lowest average (8.75 g.kg^{-1}). Different results were found by Campos et al. (2016) who observed the lowest levels of TOC in the native forest area, and the highest levels in the pasture area in relation to the native forest area. Enck et al. (2020) also found higher levels of organic carbon in the native forest area. According to Loss et al. (2015) and Mantovanelli et al. (2015), these results are due to the greater contribution of plant residues associated with its quality, in addition to the non-disturbing of the native forest.

Table 3: Descriptive statistics of 0.00-0.10 m and 0.10-0.20 m depth and soil density (Ds), total organic carbon (TOC), and carbon stock (EST. C) in the areas of native forest and pasture in União Bandeirantes, Rondônia state

Parameters	Ds	TOC	EST. C	Ds	TOC	EST. C	Ds	TOC	EST. C
	kg.dm^{-3}	g.kg^{-1}	t.ha^{-1}	kg.dm^{-3}	g.kg^{-1}	t.ha^{-1}	kg.dm^{-3}	g.kg^{-1}	t.ha^{-1}
Depth 0,00-0,10 m									
	Forest			Brachiaria			Mombaça		
Maximum	1.41	35.44	36.68	1.66	34.22	48.58	1.57	31.35	43.80
Minimum	0.88	15.96	19.46	1.03	13.90	15.57	1.00	8.94	12.07
Average	1.16 c	23.88 a	27.47 a	1.39 a	21.46 b	29.52 a	1.32 b	21.58 b	28.31 a
Median	1.18	24.20	26.49	1.37	21.28	28.26	1.34	21.55	28.51
CV%[1]	11.34	17.49	14.73	11.35	22.64	21.62	10.46	22.60	22.41
Assimetry	-0.16	0.36	0.29	-0.24	0.77	0.66	-0.52	0.17	0.29
Kurtosis	-0.97	-0.09	-0.67	-0.63	0.56	0.60	-0.27	-0.32	0.01
KS[2]	0.09*	0.08*	0.11*	0.09*	0.07*	0.11*	0.10*	0.09*	0.08*
Depth 0,10-0,20 m									
	Forest			Brachiaria			Mombaça		
Maximum	1.66	24.72	33.35	1.72	1315	20.52	1.56	17.27	22.62
Minimum	1.11	13.34	19.07	1.16	3.71	5.23	1.26	6.37	8.89
Average	1.40 c	18.09 a	25.20 a	1.51 a	8.75 c	13.19 c	1.45 b	10.65 b	15.33 b
Median	1.40	17.66	24.65	1.53	9.05	13.17	1.46	10.53	15.28
CV%[1]	7.25	14.05	13.03	7.54	23.64	24.32	5.16	23.55	21.87
Assimetry	-0.13	0.43	0.48	-0.57	-0.46	-0.27	-0.64	0.39	0.12
Kurtosis	0.66	-0.31	-0.25	0.22	-0.23	-0.19	-0.23	-0.17	-0.61
KS[2]	0.07*	0.09*	0.09*	0.12*	0.09*	0.05*	0.11*	0.07*	0.07*

[1] CV: coefficient of variation; [2]KS: Kolmogorov-Smirnov normality test, significant at 5% probability. Mean followed by the same letter on the line for the same attribute in each area does not differ statistically from each other by the Tukey test at 5% probability.

For carbon stock (EST. C), at a depth of 0.00-0.10 m there was no statistical difference between the areas, with the highest values being observed in the areas of braquiaria and mombaça (29.52 and 28.31 t.ha^{-1}) and lower value in the forest area (28.31 t.ha^{-1}), this result can be attributed to greater soil compaction in pasture areas, which significantly contributes to the increase in soil mass per unit of volume. At a depth of 0.10-0.20 m, there was a statistical difference between the areas studied, with the highest value observed in the area and forest (25.20 t.ha^{-1}) and the lowest value in the area of brachiaria (13.19 t.ha-1). The results found at a depth of 0.10-0.20 m corroborate with Freitas et al. (2018) and Enck et al. (2020) who found higher levels of EST. C in native forest area. Thus, the EST. C is found at lower levels in pasture areas, when comparing the native forest area with managed areas, since agricultural practices reduce EST. C in the soil (Freitas et al., 2018).

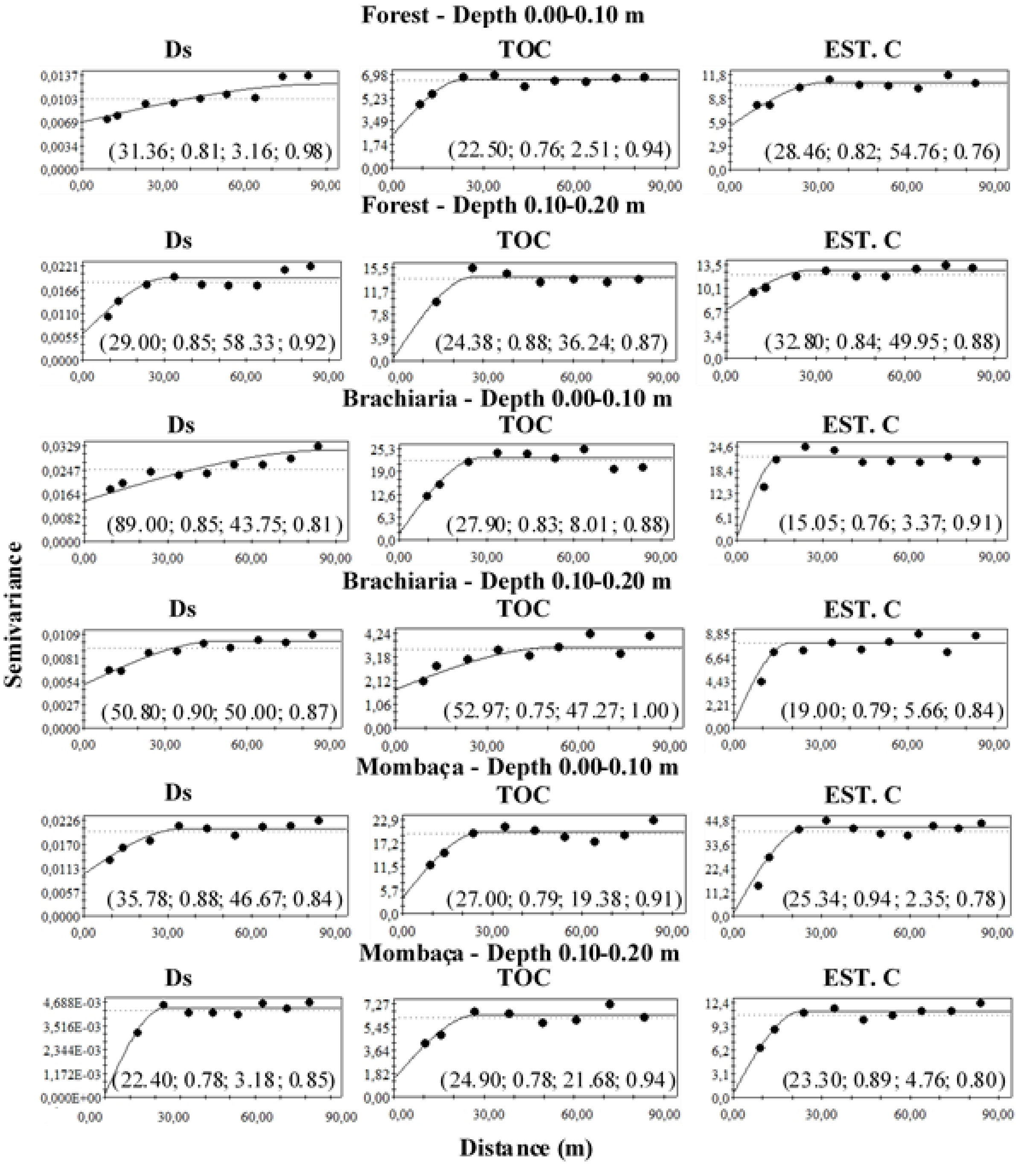

Figure 2. Semivariograms of soil attributes in an area of natural forest, Brachiaria and Mombaça, at depths of 0.00-0.10 m and 0.10-0.20 m, in the municipality of União Bandeirantes. Geostatistical parameters in parentheses are respectively: range (m); determination coefficient (R^2); degree of spatial dependence (GDE); and cross-validation (VC).

Through the semivariograms, it was possible to study the spatial variability of organic carbon and carbon stock, at depths of 0.00-0.10 and 0.10-0.20 m, which are shown in Figure 2. The model adjusted for the variables was the spherical. This result corroborates with Oliveira et al. (2013), in which they found the spherical model for soil attributes. Spherical models describe soil properties with high spatial continuity, that is, less erratic at short distances (Isaaks and Srivastava, 1989). The coefficient of determination (R^2) and cross validation (VC) oscillate, respectively, from

0.76 to 0.94 and 0.76 to 0.98 in the depth of 0.00-0.10 m and from 0.75 to 0 .94 and 0.78 to 1.00 at a depth of 0.10-0.20 m.

It is possible to observe that most attributes showed a degree of spatial dependence (GDE) between strong (<25%) and moderate (26 to 75%). Concerning to Ds, moderate GDE was observed for most of the studied areas, except in the forest area at a depth of 0.00-0.10 m in the mombaça area at a depth of 0.10-0.20 m which presented GDE strong. For TOC, strong GDE was observed for most areas, except for forest and brachiaria at a depth of 0.10-0.20 m, which showed moderate GDE. EST. C presented strong GDE in the pasture areas and moderate in the forest area, in the two studied depths. These results corroborate with Alho et al. (2014), who studying the variability of EST. C Cambisol and Ultisol in Amazonas state, observed strong and moderate spatial dependence. As recommended by Cambardella et al. (1994), the variables that show strong spatial dependence are influenced by intrinsic factors of the soil, such as relief, source material and climate. And the variables that present moderate spatial dependence are related to the soil management.

The range is an important parameter for geostatistics in the interpretation of semiovariograms once it is the limiting distance of spatial dependence. Thus, the spatial behavior of the variables becomes completely random from this distance (Leite et al., 2011; Soares et al., 2011; Soares et al. al., 2018). Ds in the brachiaria area, at a depth of 0.00-0.10 m, presented the smallest range (22.40 m), however, in the mombaça area, at a depth of 0.10-0.20 m, the largest range (89.00 m). This greater and lesser variability, observed in pasture areas, is related to grazing intensity and also to grazing preference zones, which, due to animal trampling, generate points with high and others with low Ds (Alencar et al., 2016).

The TOC showed the highest range value (52.97 m) in the brachiaria area at a depth of 0.10-0.20 m and the lowest value (22.50 m) in the forest area at a depth of 0.00-0.20 m. for EST. C, higher values (32.80 m) were observed in the forest area at a depth of 0.10-0.20 m and lower values (15.05 m) in the brachiaria area at a depth of 0.00-0.10 m. The attributes that presented higher values of range indicate that they presented less spatial variability and the distribution is homogeneous, while the values of low ranges have a greater spatial variability and heterogeneous distribution.

The kriging maps of the soil attributes studied, which were built from the adjustments of the semivariograms, are shown in figures 3 and 4. The maps are fundamental pieces, as they make it possible to verify and relate spatially the attributes, in addition, they help in the correct land use and management (Barbosa et al., 2019; Guimarães et al., 2016).

In the native forest area, all attributes exhibit spatial heterogeneity in their distribution, this variability is also observed at the lowest range values found in it. This greater variability in this area can be attributed to the micro-reliefs, which, due to the direction of the water flow, take nutrients to the lower areas (Artur et al., 2014). The density showed greater accumulation in the central region and in the lower region, however, it was the area that presented lower contents when compared to the pasture areas. Observing the spatial behavior of the TOC, it appears that the highest levels of this attribute are inverse to the highest levels of density.

Luciano et al. (2010) and Schroeder et al. (2017) observed that these attributes have a significant inverse relationship, as the higher the organic carbon content, the lower the density of the soil. The EST. C map is similar to one of TOC, and it is possible to observe that in almost all places where there are higher levels of TOC, there are also higher levels of EST. C and in the same way where there is less TOC, there are also less EST. C levels in that area.

In both pasture areas, Ds are practically verified in the higher regions of the relief, corroborating Campos et al. (2013) and Alho et al. (2014), and the D map in the brachiaria area showed the lowest variability. However, these two areas presented higher values compared to the forest area, which must be related to inadequate management with excessive trampling of animals (Soares et al., 2015). Regarding the TOC, most of the highest values can be seen in the lower part of the relief, with the map of the brachiaria area showing less variability. Looking at EST.C maps, it is possible to notice that the area of mombaça presented a more homogeneous distribution and with less variability, and the points where they present more values of ESCT. C are also related to the highest TOC values, as they follow the same spatial distribution. Santos et al. (2017) also observed that, in EST. C values, there was the same trend obtained for the TOC values.

Based on geostatistics through kriging maps, it was possible to observe the formation of five levels of specific management for each environment, allowing the choice of less aggressive managements to the soil, increasing the efficiency of carbon accumulation through the organic matter produced by the vegetations and thus reducing the impact of agriculture in these environments (Matias et al., 2019).

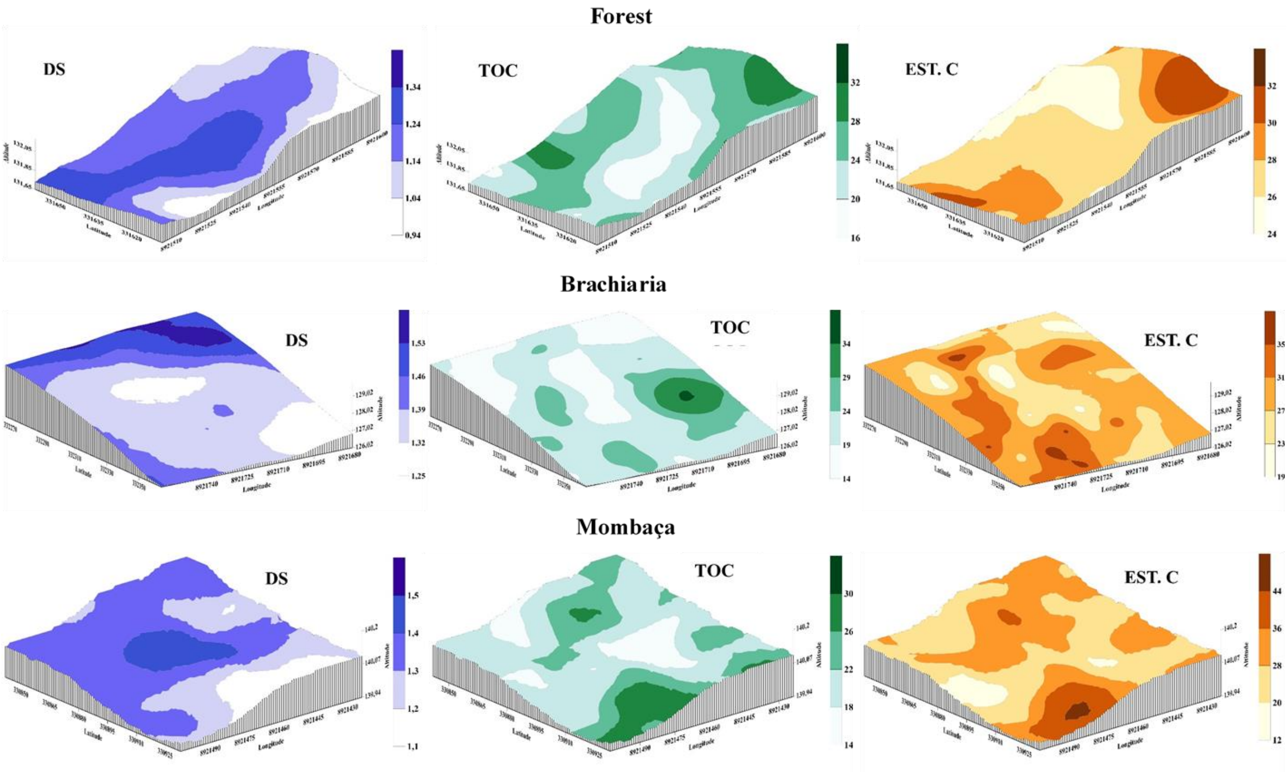

Figure 3. Kriging maps of soil attributes in the area of Forest, Brachiaria and Mombaça, at a depth of 0.00-0.10 m, in União Bandeirantes, RO state.

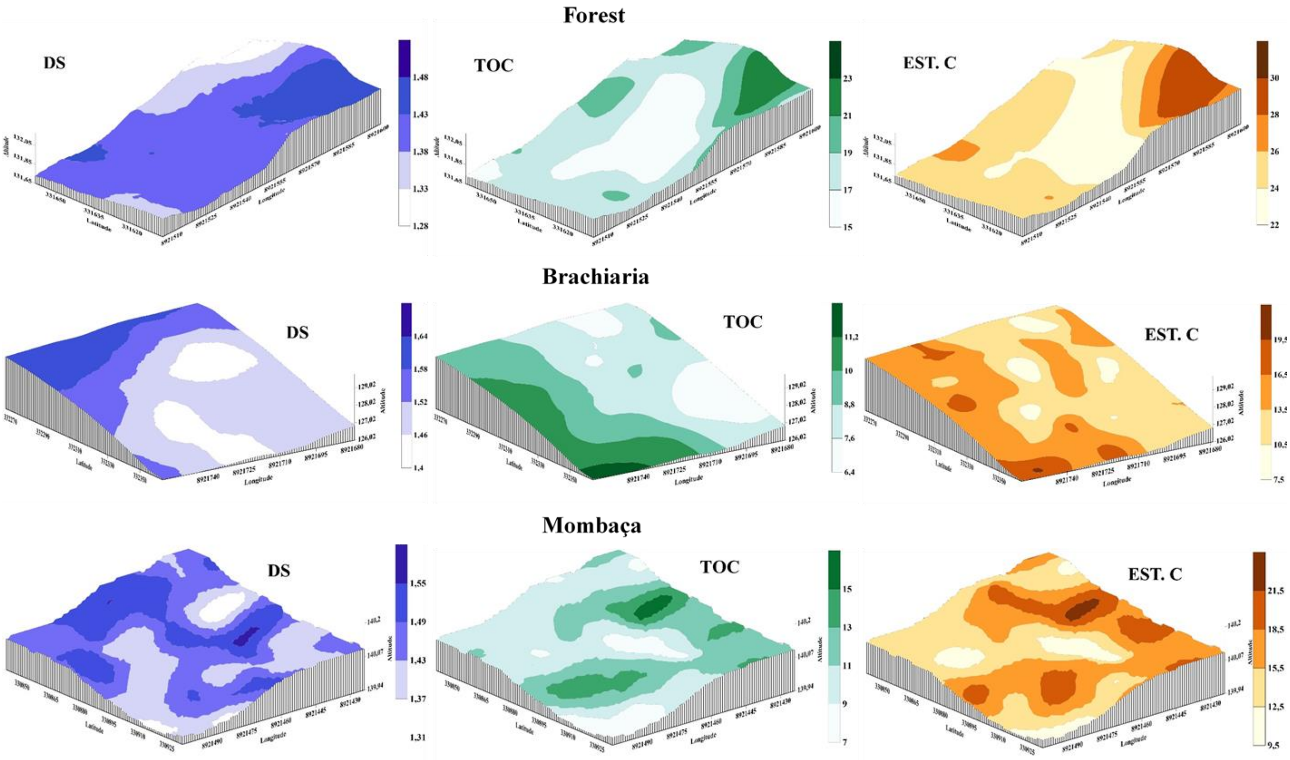

Figure 4. Kriging maps of soil attributes in an area of Forest, Brachiaria and Mombaça, at a depth of 0.10-0.20 m, in União Bandeirantes, RO state.

Conclusions

The native forest area had the highest total organic carbon contents and the lowest soil density compared to pasture areas. The forest area has a greater capacity to store carbon in depth than pasture areas. The carbon stock in pastures on the soil surface is more influenced by soil compaction from the trampling of large animals.

All soil attributes showed spatial dependence in all areas and depths, with some attributes showing greater variability. Through the kriging maps it was possible to spatially relate the attributes, visualize the spatial distribution and verify the management zones for the areas.

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