Original Article

PHYSICAL AND GEOSPATIAL ATTRIBUTES OF INCEPTISOLS AND ULTISOLS UNDER NATIVE VEGETATION IN HUMAITÁ, AM, BRAZIL

ATRIBUTOS FÍSICOS E GEOESPACIAIS DE CAMBISSOLO E ARGISSOLO DE MATA NATIVA EM HUMAITÁ, AM

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ABSTRACT: Natural grasslands with savannah-like characteristics associated to forest mosaics are found within Southern and Eastern Amazonas, Western Rondônia and Northern Roraima, being conditioned to local edaphic factors. The aim of this study was to assess both physical and geospatial attributes of an Cambisol under natural grasslands and an Ultisol under a forest fragment in Humaitá - AM, Brazil. In each area, we established a sampling grid in the dimensions of 70 × 70 m, with regular sampling spacing of 10 m and three collection depths: 0.0-0.05, 0.05-0.10 and 0.10-0.20 m, totaling 192 sampling points. Macroporosity (MaP), microporosity (MiP), bulk density (Ds) and total porosity (TP) were determined by soil samples with preserved structure, using a volumetric ring. Soil resistance to penetration (SRP) was measured by an automatic penetrometer after being subjected to a 0.006 MPa tension. Data were submitted to descriptive statistics and geostatistics analysis. The soil under natural grasslands showed values considered critical of Ds, SRP, MaP at all evaluated depths, with significant values at 0.10-0.20 m layer of 1.54 kg dm^{-3}; 2.08 MPa and 0.05 m^3 m^{-3}, respectively. Ultisol under the forest fragments showed higher range values and consequently greater geospatial continuity due to the assessed physical attributes, since this soil has a greater stability of its physical structure. Based on the physical properties of the soil, structural function ineffectiveness of the Ultisol is a key factor for the occurrence of grassland in this region.

KEYWORDS: Soils attributes. Natural grasslands. Forest.

INTRODUCTION

Western Amazon holds 42.97% of the land within the Legal Amazon area. Overall, it has different physiographies, namely wetlands, dry land, dense forest environments, open forests associated with palm trees and with bamboos, bamboo forests, campinaranas, and various types of natural fields. According to Freitas et al. (2002), in Southern and Eastern Amazonas, Western Rondônia and Northern Roraima, natural fields have savannah traits associated to forest mosaic, which are subjected to local soil factors (CAMPOS et al., 2010).

Notwithstanding phytophysionomic diversity, Campos et al. (2012) highlighted a great variety of interrelated soils within landscape, such as Oxisols under dense forests in plateau areas, Ultisols in forest mosaics, Inceptisols under natural fields (cerrado, with few trees) and Entisols under natural fields (grassy field, with predominance of grasses and sedges). They are interrelated along the landscape, whose high silt content, groundwater upwelling and savannah-like vegetation are striking features of this region.

According to Martins et al. (2006), morphological and hydro-physical soil attributes experience more changes with small variations in terrain, so that the forest soil is deeper and, consequently, has higher volume of water storage and infiltration, while the opposite conditions favor natural grasslands.

Aquino et al. (2015) and Campos et al. (2011) asserted that terrain micro-variations can promote geospatial variation of soil attributes, even when the areas seem to be homogeneous (Oliveira et al., 2015a), affecting crop yield and soil analysis accuracy, which uses sample mean of the area. Moreover, Souza et al. (2006) stated that extra statistical analyses are needed to measure such variations, because most of the soils change over time and space.

Within this context, geostatistical methods are being widely used, since they check the geographical coordinates of sample points in line with the soil properties within a geospatial domain (KAMIMURA et al., 2013; CORTEZ et al., 2011; SILVA et al., 2010) and, the occurrence of the assessed attributes enable the generation of kriging

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maps that display dynamics of soil attributes over the area, being an important aid for decision making regarding environmental and agricultural use (AQUINO et al., 2015; OLIVEIRA et al., 2013).

This research aimed to assess physical and geospatial attributes of Cambisol and Ultisol under grassland and forest areas in Humaitá County – AM, Brazil.

MATERIAL AND METHODS

The study was carried in two locations, Humaitá (Southern Amazonas State) and around border areas with Northern Rondônia State, at the geographical coordinates of 7º 30' 24" S and 63º 04' 56" W, respectively. The area has two typical vegetal formations that are dense forests and natural grasslands. According to Köppen, the local climate belongs to the group A (Rainy Tropical Climate) and Am type, which stands for areas with a short dry season, a rainy season from October to June and mean annual rainfall around 2,250 and 2,750 mm. Annual mean temperatures range from 25 to 27 ºC and air relative humidity between 85 and 90 %.

The region is geologically formed from undifferentiated alluvium, which are chronologically derived from Holocene period and its sediments arising from two sedimentation cycles: a) inferior sandbanks, representing pluvio-fluvial sedimentation and, b) higher clayey sediments indicating lake sedimentation (CAMPOS et al., 2010).

We chose high field and forest areas to perform this study, since they are the most frequent within the region. It was built a sampling grid in the dimensions of 70 × 70 m in each area, with a 10-m regular spacing between the points, totaling 64 sampling points in each mesh. The sampling points were georeferenced with a GPSMAP 76CS (Garmin International, USA) with an accuracy <10 m.

Macro and microporosity, bulk density and total porosity were determined by preserved structure soil samples, which were collected with a volumetric ring at 0.0-0.05; 0.05-0.10 and 0.10-0.20 m depths. In the laboratory, samples were prepared by withdrawing soil excess from the ends of the rings and then saturated by gradual increase of water on a plastic tray up to reach approximately ⅔ the sample height. After saturation, they were weighed and microporosity determined by the tension table method, being subjected to a 0.006 MPa tension (EMBRAPA, 1997).

After reaching equilibrium at a matric potential of -0.006 MPa, the samples were weighed and then was measured soil penetration resistance (RP), using an electronic penetrometer Model MA-933, trade mark Marconi, equipped with a cell load of 200 N, with cone shaft 4 mm base diameter and half-angle of 30 degrees, a constant speed of penetration 0.1667 mm s -1, and receiver interface coupled to a computer for registration of readings using a specific product software. The samples from 5 mm of the upper and lower samples were discarded in order to eliminate the effect of the periphery of the sample

After reaching equilibrium at a matric potential of -0.006 MPa, the samples were weighed and then soil resistance to penetration (SRP) was measured, using an electronic penetrometer model MA-933 (Marconi Equipment, Piracicaba, SP, Brazil), with a load cell of 200 N, rod with a 4-mm base diameter cone and 30º half-angle. The equipment operated at a constant penetration speed of 0.1667 mm s^{-1}. A receiver and an interface coupled to a computer recorded readings using a specific software. The upper and lower 5 mm of each sample were discarded to eliminate edge effect (BRADFORD, 1986).

After SRP determination, samples were dried in an oven at 105 to 110 ºC for 48 h to ascertain volumetric humidity and Ds by the volumetric ring method. TP and MaP were determined according to method proposed by Embrapa (1997).

Data were submitted to descriptive analysis, through which it was determined mean, maximum and minimum values, asymmetry and Kurtosis coefficient, variation coefficient (VC) and data frequency distribution. This analysis was performed by Minitab 14 statistical software (MINITAB, 2000).

Geostatistics was used to characterize spatial variability. Experimental semivariogram was estimated by the equation (1).

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

Wherein: γ(h) - semivariance at an h distance; N(h) – number of pairs in a semivariance calculation; $Z(x_i)$ - Z attribute value at x_i; $Z(x_i+h)$ - Z attribute value at an h distance from x_i.

Experimental semivariogram were chosen based on the number of pairs within the semivariance calculation of the first lags, with a clearly defined sill (BURROUGH and MCDONNEL, 2000) and the result of Jack Knifing technique (VAUCLIN et al., 1983).

After mathematical model fit, data were interpolated through kriging. GS^+ software

performed geostatistical analysis and Surfer 8.00 the kriging maps.

RESULTS AND DISCUSSION

Table 1 shows the descriptive statistics of soil physical attributes for both areas. Mean and median have similar values at the different evaluated depths and areas. It reveals a normal or symmetrical data distribution. Such results corroborate with findings of Kamimura et al. (2013).

Asymmetry and Kurtosis are data distribution indicators; however, they are more sensible to extreme values than mean and median that, when near to zero indicate data normality and, as consequence, semivariogram best fit (CORTEZ et al., 2011). Thus, Table 1 shows that asymmetry and Kurtosis values of most variables are near to zero in both depths and areas.

According to the results of Kolmogorov-Smirnov normality test, only the MaP at 0.05-0.10 and 0.10-0.20 m depths, SRP and TP at 0.10-0.20 m depth, in the natural grassland and MaP at 0.10-0.20 m in the forest were significant by the test, i.e., they did not present normality.

For comparison purposes, it was adopted variation coefficient limits proposed by Warrick & Nielsen (1980) to classify the variability of studied attributes, being: VC <12 %; 12 % < VC < 60 % and VC > 60 %, which are considered low, medium and high, respectively. This way, Ds, MiP and TP at 0.0-0.05; 0.05-0.10 and 0.10-0.20 m depths in both environments were low. These results are similar to those found by Lima et al. (2009), except for SRP and MaP in both environments and at the different depths, which presented moderate variability; and MaP at 0.10-0.20 m depth in the natural grassland has high variability.

Table 1. Descriptive statistics and geostatistics of physical attributes in soils under natural grasslands and forest in Humaitá – AM, Brazil.

Descriptive Statistics	Haplic Cambisol/natural grasslands					Red Ultisol/forest				
	RP	Ds	MaP	MiP	VTP	RP	Ds	MaP	MiP	VTP
	MPa	kg dm^{-3}		$m^3\ m^{-3}$		MPa	kg dm^{-3}		$m^3\ m^{-3}$	
					0,0 – 0,05 m					
Mean	1.98	1.37	0.08	0.36	0.45	0.77	1.16	0.14	0.37	0.51
Median	1.99	1.37	0.08	0.37	0.45	0.76	1.15	0.14	0.37	0.50
Maximum	2.73	1.51	0.16	0.41	0.51	1.25	1.32	0.20	0.41	0.57
Minimum	1.12	1.21	0.02	0.31	0.38	0.40	1.00	0.10	0.33	0.44
[1]CV (%)	20.65	5.64	45.69	6.36	7.13	27.59	6.10	16.22	5.09	5.15
Asymmetry	-0.27	-0.10	0.25	-0.11	-0.06	0.26	0.07	0.48	0.15	0.11
Kurtosis	-0.59	-0.86	-0.87	-0.55	-0.56	-0.53	-0.08	-0.16	-0.30	-0.04
[2]d	0.08^{ns}	0.05^{ns}	0.05^{ns}	0.05^{ns}	0.04^{ns}	0.05^{ns}	0.05^{ns}	0.05^{ns}	0.04^{ns}	0.08^{ns}
					0,05 – 0,10 m					
Mean	2.07	1.49	0.06	0.35	0.41	0.77	1.20	0.14	0.37	0.51
Median	2.14	1.50	0.05	0.35	0.41	0.79	1.21	0.14	0.37	0.51
Maximum	2.61	1.63	0.14	0.40	0.48	1.32	1.34	0.22	0.40	0.56
Minimum	1.28	1.28	0.02	0.29	0.37	0.30	0.89	0.10	0.30	0.42
[1]CV (%)	16.75	5.07	49.41	6.55	6.68	28.55	7.79	20.57	5.29	5.07
Asymmetry	-0.50	-0.21	1.12	-0.12	0.43	0.16	-1.09	0.63	-0.61	-0.44
Kurtosis	-0.49	-0.30	1.03	0.04	-0.20	0.07	1.38	-0.29	1.08	0.98
[2]d	0.08^{ns}	0.07^{ns}	0.12*	0.02^{ns}	0.06^{ns}	0.08^{ns}	0.09^{ns}	0.07^{ns}	0.03^{ns}	0.04^{ns}
					0,10 – 0,20 m					
Mean	2.08	1.54	0.05	0.24	0.29	0.85	1.26	0.13	0.37	0.50
Median	2.02	1.54	0.04	0.24	0.28	0.86	1.27	0.14	0.37	0.50
Maximum	3.36	1.72	0.14	0.27	0.38	1.42	1.44	0.22	0.40	0.57
Minimum	1.26	1.35	0.01	0.22	0.24	0.25	0.99	0.08	0.33	0.45
[1]CV (%)	22.69	5.88	65.40	5.69	11.87	33.57	7.79	21.87	4.14	5.12
Asymmetry	0.86	-0.21	0.99	0.26	1.01	0.08	-0.46	1.08	-0.23	0.61
Kurtosis	0.55	-0.61	0.15	-0.98	0.52	-0.74	0.30	1.30	-0.37	0.30
[2]d	0.11*	0.06^{ns}	0.14*	0.06^{ns}	0.12*	0.07^{ns}	0.05^{ns}	0.10*	0.04^{ns}	0.05^{ns}

SRP: soil resistance to penetration; Ds: soil bulk density; MaP: macroporosity; MiP: microporosity; TP: total porosity; [1]VC: variation coefficient; [2]d: Kolmogorov-Smirnov normality test; *significant at 5 % probability.

Table 2 introduces the geostatistical parameters. Exponential and spherical were the semivariogram models that best fitted soil physical attributes in grasslands and forest, respectively. Nevertheless, for some attributes as T and Ds at 0.0-0.05 m and 0.05-0.10 m depths, respectively, regarding forest and natural grasslands, a pure nugget effect (PNE) was encountered, that is, there was no spatial dependence for the studies sampling distance (OLIVEIRA et al., 2015 a). PNE points out for non-explained or non-detected variability, which may occur due to measurement or sampling errors, or even attribute micro-variations (CAMBARDELLA et al., 1994).

Several results indicate exponential and spherical models are the ones best fitted for soil physical attributes (AQUINO et al., 2015; MENDES et al., 2006). However, it is noteworthy to mention that the models were adjusted through determination coefficient (R^2), which were above 0.75; and cross-validation (CV) values were on average for both areas superior to 0.65, which means that these models are the most representative, corroborating to Chig et al. (2008) and Silva et al. (2010).

Table 2. Geostatistics of physical attribute of soil under natural grassland and forest in Humaitá – AM, Brazil.

Geostatistics	Haplic Cambisol/natural grasslands					Red Ultisol/forest				
	RP	Ds	MaP	MiP	VTP	RP	Ds	MaP	MiP	VTP
	MPa	kg dm^{-3}		m^3 m^{-3}		MPa	kg dm^{-3}		m^3 m^{-3}	
					0,0 – 0,05 m					
Model	Exp.	Exp.	Exp.	Esf.	Exp.	Exp.	Esf.	Esf.	Exp.	Lin.
Reach (m)	24.0	22.0	26.0	21.0	22.0	43.0	30.0	51.0	33.0	–
$^1R^2$	0.75	0.86	0.89	0.85	0.87	0.95	0.96	0.97	0.92	–
^{2}GDE (%)	11.3	14.0	13.0	17.0	13.6	18.0	31.8	45.3	11.6	EPP
^{3}VC	0.79	0.60	0.60	0.87	0.63	0.78	0.68	0.82	0.74	–
					0,05 – 0,10 m					
Model	Exp.	Lin.	Exp.	Exp.	Exp.	Esf.	Exp.	Exp.	Exp.	Esf.
Reach (m)	20.0	–	36.0	34.0	23.0	36.0	43.0	22.0	22.0	26.0
$^1R^2$	0.75	–	0.95	0.88	0.66	0.85	0.99	0.92	0.87	0.90
^{2}GDE (%)	12.0	EPP	9.2	15.9	14.3	40.4	15.0	12.7	10.2	12.0
^{3}VC	0.79	–	0.67	0.60	0.78	0.77	0.55	0.61	0.80	0.86
					0,10 – 0,20 m					
Model	Esf.	Exp.	Exp.	Exp.	Exp.	Exp.	Esf.	Esf.	Exp.	Esf.
Reach (m)	33.0	41.0	34.0	25.0	29.0	36.0	34.0	38.0	33.0	26.0
$^1R^2$	0.85	0.93	0.91	0.88	0.86	0.93	0.98	0.97	0.89	0.86
^{2}GDE (%)	14.6	14.7	13.3	10.0	12.5	17.0	37.6	32.8	14.2	23.0
^{3}VC	0.76	0.86	0.72	0.76	0.77	0.60	0.84	0.58	0.65	0.53

SRP: soil resistance to penetration; Ds: soil density; MaP: macroporosity; MiP: microporosity; TP: total porosity; Sph. spherical; Exp.: exponential; Lin: linear; $^1R^2$: correlation coefficient; ^{2}SDD: spatial dependence degree; ^{3}CV: cross-validation.

Spatial dependence degree (SDD) of the variables was assessed according to Cambardella et al. (1994), in which: SDD values smaller than 25%, indicate strong spatial dependence; values between 25 and 75% show moderate dependence; and values higher than 75%, point weak dependence. It was assigned to the variables in natural grasslands and forest areas at the varied depths, a strong spatial dependence, except for Ds, MaP and SRP that had moderate classification at some depths (Table 2).

Semivariance stabilization occurs at a certain distance, which is referred to as spatial dependence range (a). It can be interpreted as the distance over which the values of the variables under study do not correlate. It varied from 21 to 26 m; 20 to 36 m and 25 to 41 m, at respective depths of 0.0-0.05; 0.05-0.10 and 0.10-0.20 m in natural grasslands.

In forest area, range varied from 30 to 51 m; 22 to 36 m and 26 to 38 m, at 0.0-0.05; 0.05-0.10 and 0.10-0.20 m depths, respectively. Oliveira et al. (2013) claimed that range value influences estimate quality, and this is what determines the number of values used in the interpolation. It must be highlighted that estimates obtained via ordinary kriging interpolation, using higher range values are more reliable, with maps that best represent the reality.

As for the physical characteristics of the soil properties, it was observed in the natural grasslands Ds values of 1.37, 1.49 and 1.54 kg dm^{-3} at the different depths (Table 1). Arshad et al. (1996) stated that Ds values superior to 1.40 kg dm^{-3} for medium texture and clayey soils may cause restrictions on root growth. Several authors had stated that Ds is an attribute that varies with time by

natural densification processes and management practices, decreasing soil porosity, especially macroporosity (ARAÚJO et al., 2007; CARDOSO et al., 2011).

Campos et al. (2012a) observed that Inceptisols, in natural grasslands, have a texture ranging from medium to silt-loam and grade grains in sub-angular blocks at a depth of 0.0 to 0.30 m. According to Castione et al. (2015) and Oliveira et al. (2015b), soil can become dense as a result of its textural composition, moisture regime and genesis; pointing out that at subsurface layers, it can be due to packaging of granular sediments, partially cemented, in which soils with structures in blocks or similar tend to be denser. In the present study, these characteristics delineate the likely cause of high Ds in the grasslands.

In the forest area, Ds mean value varied from 1.16 to 1.26 kg dm^{-3} at 0.0-0.05 and 0.10-0.20 m depths, respectively. Considering different types of vegetation, but with a very similar texture, it is believed that lower Ds in forest area is related to littering accumulation, as reported by Martins et al. (2006).

SRP had correlation with Ds, that is, while in the forest the SRP mean value was 0.85 MPa at 0.10-0.20 m, and 0.77 MPa for both depths; SRP values in the grasslands were higher than 2.00 MPa (Table 1). Similar results are described by Abreu et al. (2003) and Campos et al. (2012b) in Ultisols and Inceptisols, respectively. According to Tormena and Rollof (1996), SRP values equal or above 2.00 MPa are critical and can restrict root growth.

Concerning MaP, mean values in the grasslands at all depths were higher than 0.08 m^3 m^{-3}. Assis and Lanças (2005) ascertained that MaP values smaller than 0.10 m^3 m^{-3} denote inadequate aeration to meet the needs of root system and soil microorganisms. Additionally, as a result, according to Araujo et al. (2007), it reflects in a lower soil infiltration rate, and therefore favors erosion by runoff, sedimentation and pollution of water reservoirs, resulting from sediment deposition carried by floods from agricultural sector activities.

In the natural grasslands, MiP average value was 0.36 m^3 m^{-3} at superficial layers, being similar to those found in the forest; however, there was a reduction to 0.24 m^3 m^{-3} at the 0.10-0.20 m layer. On the other hand, in the forest, invariable values of MaP and MiP were 0.14 and 0.37 m^3 m^{-3}, respectively; and associated with SRP and Ds values characterize soil physical stability for that environment (MARTINS et al., 2006; CAMPOS et al., 2012a).

As presented in Figure 1 and 2, geospatial distribution of soil attributes was assessed by kriging maps. The maps of natural grasslands show a greater heterogeneity of attribute distribution, as the scale of values defined in this study (Figure 1). It is justified by a lower range of spatial dependence (Table 2) and relief micro-variations (CAMPOS et al., 2011).

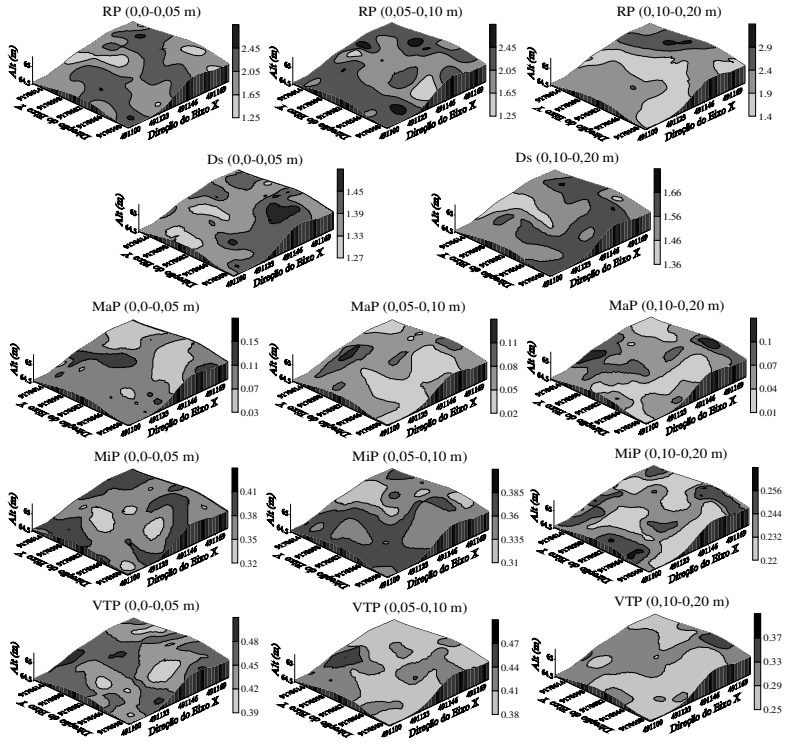


Figure 1. Kriging maps of soil physical attributes in natural grasslands at different depths.

Linear relief format in the forest, albeit with little slope facing the land central part, promoted greater continuity of soil attributes, what is confirmed by a greater range of spatial dependence (Table 2, Figure 2), which corroborates with Campos et al. (2013), who found greater spatial continuity of attributes in a forest area in the district of Manicoré-AM, Brazil. It was observed that greater values of SRP and Ds are correlated and inversely proportional to MaP in the same region (Figure 2).

The lowest MiP volume at 0.10-0.20 m depth compared to superficial layers, as well as MaP, irrespectively the evaluated layer, implies in TP reduction. These characteristics added up to the expressive values of Ds and SRP reveal inefficiency of structural functions in the natural grasslands, which distinguishes soil physical quality.

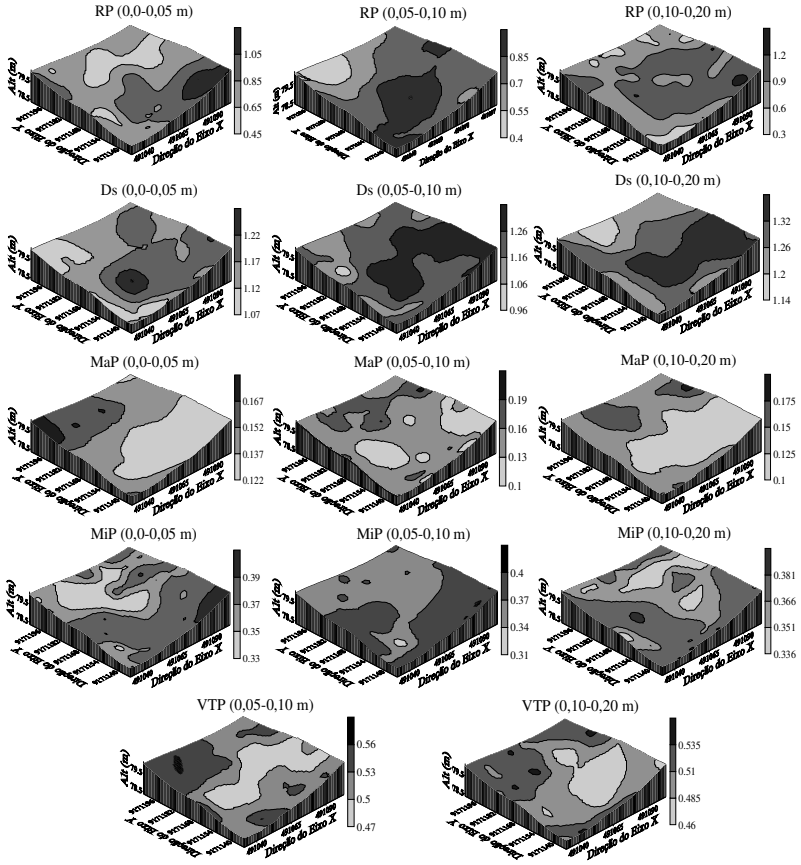


Figure 2. Kriging maps of soil physical attributes in forest at different depths.

CONCLUSIONS

Kriging maps of natural grassland area indicate that a lower continuity of the spatial dependence structure of soil attributes comes from constant relief micro-variations on this area.

Forest Ultisols showed greater values of range and, consequently, higher geospatial continuity of the physical attributes, which is related to the improved stability of this soil physical structure.

Pedogenic processes and grain size morphological characteristics in Inceptisols constitute the main factors of soil densification in natural grasslands.

Based on physical characteristics, the inefficiency of structural functions in Inceptisols is the determining factor for grassland vegetation occurrence in this region.

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RESUMO: Na porção sul e leste do Amazonas, oeste de Rondônia e norte de Roraima há ocorrência de campos naturais com características savânicas associadas a mosaicos florestais, condicionadas aos fatores edáficos locais. O

objetivo deste estudo foi avaliar os atributos físicos e geoespaciais de um Cambissolo sob campos naturais e Argissolo sob fragmento florestal em Humaitá, AM. Em cada área foi estabelecida uma malha amostral nas dimensões de 70 × 70 m, com espaçamentos regulares de amostragem de 10 m e três profundidades de coleta: 0,0-0,05; 0,05-0,10 e 0,10-0,20 m, totalizando 192 pontos de coleta. Para as determinações da macroporosidade (MaP), microporosidade (MiP), densidade do solo (Ds) e volume total de poros (VTP) foram coletadas amostras com estrutura preservada, utilizando-se anéis volumétricos. Após serem submetidos a uma tensão de 0,006 MPa, as mesmas amostras foram utilizadas para medir a resistência do solo à penetração (RP), utilizando um penetrógrafo eletrônico. Os resultados foram submetidos às análises estatística descritiva e geoestatística. O solo sob campo natural apresentou valores considerados críticos de Ds, RP, MaP em todas as profundidades avaliadas, obtendo-se valores mais expressivos na profundidade de 0,10-0,20 m, da ordem de 1,54 kg dm^{-3}; 2,08 MPa; e 0,05 m^3 m^{-3}, respectivamente. O Argissolo do fragmento florestal apresentou maiores alcances e consequente maior continuidade geoespacial correlativa aos atributos físicos avaliados, mediante a maior estabilidade da estrutura física desse solo. Com base nas características físicas do solo, a ineficiência das funções estruturais do Cambissolo é o fator determinante da ocorrência de vegetação campestre nessa região.

PALAVRAS-CHAVE: Atributos do solo. Campo natural. Floresta.

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