SOLOS AMAZÔNICOS:

Qualidade estrutural, físico, químico e suas correlações geoespacial no Sul do Amazonas

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Solos Amazônicos: atributos físicos, químicos, erodibilidade e suscetibilidade magnética

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APRESENTAÇÃO

Os estudos sobre solos da Amazônia, especialmente no Sul-sudeste do Amazonas iniciaram-se com a criação do Grupo de Pesquisa "Solos e Ambiente Amazônico" em 2009 com a implantação do Instituto de Educação, Agricultura e Ambiente da Universidade Federal do Amazonas em Humaitá, naquela ocasião conseguiu-se congregar um pequeno grupo de estudantes e professores com trabalhos voltados para estudar as relações entre Solos e Ambiente.

O grupo Solos e Ambiente Amazônico foi crescendo e se consolidando à medida que os Projetos foram sendo aprovados (FAPEAM e CNPq), aqui destaca-se que o projeto intitulado "Impactos no solo da conversão floresta-uso agropecuário na região Sul do Amazonas" aprovado junto ao Edital - FAPESP/FAPEAM em 2009, possibilitou a criação de infraestrutura necessária a pesquisa. Em 2013 duas Dissertações de Mestrado foram defendidas junto ao Programa de Pós-graduação em Agronomia Tropical, a saber: i) Variabilidade espacial de atributos físicos e químicos em Cambissolo e Argissolo na região de Humaitá, AM (Leandro Coutinho Alho); ii) Atributos do solo e emissão de CO2 em uma área de Terra Preta Arqueológica sob cultivo de cacau na região de Apuí, AM (Douglas Marcelo Pinheiro da Silva) com total suporte da infraestrutura adquirida.

Os projetos de pesquisa aprovados auxiliaram/auxiliam o Grupo de Pesquisa a prover de equipamentos o Laboratório de Solos e Nutrição de Plantas e o Laboratório de Fitotecnia, o que possibilitou a realização de diversas analises vinculados a Projetos de Iniciação Científica, Trabalhos de Conclusão de Curso de Graduação, Dissertações de Mestrado e Teses de Doutorado favorecendo a geração de conhecimento e formação de recursos humanos altamente qualificadas no interior da Amazônia. Além disso, o grupo de pesquisa também realizou Eventos Científicos e de Popularização da Ciência e publicação de Livros.

Atualmente o grupo de pesquisa coordena diversos Projetos de Pesquisa e de Popularização da Ciência, bem como orientação de trabalhos em nível de Graduação e Mestrado. Dessa forma é possível apresentar esta **Coletânea de Trabalhos em Solos e Ambiente Amazônico** oriundo de várias Dissertações de Mestrado e Tese de Doutorado. Além disso, foi possível fazer parcerias e trazer para este material iniciativas em outras regiões e instituições para colaborar com este trabalho.

O material apresentado está relacionado a duas áreas da Ciência do Solo, a primeira referente aos estudos de Solo no Tempo e no Espaço e a segunda relacionada a Processos e Propriedades do Solo. Importante destacar que no primeiro caso há investigações nos diferentes tipos de material de origem, relevo e suas influencias nos distintos tipos de solos existentes na Amazônia. E no segundo caso estudou-se as interferências das mudanças da cobertura vegetal (usos e manejos) nos atributos físicos e químicos do solo.

Agradecemos à Fundação de Amparo à Pesquisa do Estado do Amazonas (FAPEAM) que apoiou a realização do ***III Simpósios de Ciência do Solo da Amazônia Ocidental***, sendo possível apresentar o material intitulado: "**Solos Amazônicos: atributos físicos, químicos, erodibilidade e suscetibilidade magnética**".

Milton César Costa Campos. José Maurício da Cunha

SUMÁRIO

CAPÍTULO 1

SPATIAL VARIABILITY OF SOIL ERODIBILITY IN PASTURES AND FOREST AREAS IN THE MUNICIPALITY OF PORTO VELHO, RONDÔNIA

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ABSTRACT: Erodibility is a characteristic of the soil that represents the susceptibility with which its particles from the most superficial layer are taken and transported to lower places by erosive agents, causing environmental and economic damages. The objective of this work was to estimate soil erodibility in pastures and forest areas in the municipality of Porto Velho-Rondônia In the field, three areas with different types of vegetation were selected, one with brachiaria, another with mombaça grass, and a third in native forest. In areas with pastures, a sampling mesh of equal sizes was outlined (90 m x 60 m), and in the forested area an approximate sampling mesh (90 m x 50 m), with a regular spacing of 10 m between the samples points for both areas. The sampling was done at the crossing points of the mesh at a depth of 0.0-0.2 m, composing 70 sample points in the areas with pastures and 60 sample points in the forest area, totaling 200 samples. Then, laboratory analyzes were carried out to determine the texture followed by the fractionation of the sand, and the organic carbon followed by the estimate of the organic matter of the soil. The erodibility factors were calculated using indirect prediction models, and then, univariate, geostatistical and multivariate techniques were applied. The pastures environments differed from the forest environment. However, the mombaça grass area functions as an intermediate environment between the forest and the brachiaria, being closer to the forest environment.

KEYWORDS: Factors erodibility, kriging, principal components.

VARIABILIDADE ESPACIAL DA ERODIBILIDADE DO SOLO EM ÁREAS DE PASTAGENS E FLORESTA NO MUNICÍPIO DE PORTO VELHO, RONDÔNIA

RESUMO: A erodibilidade é uma característica do solo que representa a susceptibilidade com que suas partículas da camada mais superficial são levadas e transportadas para locais mais

baixos por agentes erosivos, causando danos ambientais e econômicos. O objetivo deste trabalho foi estimar a erodibilidade do solo em áreas de pastagens e florestas no município de Porto Velho-Rondônia. Em campo, foram selecionadas três áreas com diferentes tipos de vegetação, uma com braquiária, outra com capim mombaça e uma terceira em floresta nativa. Nas áreas com pastagens, foi delineada uma malha amostral de tamanhos iguais (90 m x 60 m), e na área de floresta uma malha amostral aproximada (90 m x 50 m), com espaçamento regular de 10 m entre os pontos amostrais para ambas as áreas. A amostragem foi realizada nos pontos de cruzamento da malha na profundidade de 0,0-0,2 m, compondo 70 pontos amostrais nas áreas com pastagens e 60 pontos amostrais na área de floresta, totalizando 200 amostras. Em seguida, foram realizadas análises laboratoriais para determinação da textura seguida do fracionamento da areia, e do carbono orgânico seguida da estimativa da matéria orgânica do solo. Os fatores de erodibilidade foram calculados por meio de modelos de predição indireta e, em seguida, foram aplicadas técnicas univariadas, geoestatísticas e multivariadas. Os ambientes de pastagem diferiram do ambiente de floresta. No entanto, a área de capim mombaça funciona como um ambiente intermediário entre a floresta e a braquiária, estando mais próxima do ambiente de floresta.
PALAVRAS-CHAVE: Componentes principais, fatores erodibilidade, krigagem.

1 I INTRODUCTION

Soil erosion is a process of detachment and accelerated drag of soil particles caused by water (water erosion) or wind (wind erosion) (Demarchi et al., 2019).Erosion can be classified into: Geological or Natural erosion, which comes from natural phenomena that act continuously in the earth's crust for the benefit of the formation of the soil itself, being recognizable only over long periods of activity; and Accelerated or Anthropic erosion, which comes from the intensification of the natural erosive process due to the direct action of man on the soil-plant-atmosphere system through the insertion of practices that destroy the balance of the natural conditions of this process (Bertoni& Lombardi Neto, 1999).

According to Morgan (1995), soil erosion is basically caused by the detachment and transport of soil particles by the action of water and wind. The ease with which this process occurs is called soil erodibility, being one of the most worrying factors within agriculture because it directly and indirectly affects the plantation and the environment, being the main cause of the decline in soil fertility, even more in regions where there is greater degradation of the most fertile soil layers (Macedo et al., 2010).

To solve this problem, several researchers have proposed indirect models for predicting soil losses (in the laboratory), which make it possible to consider the spatial and temporal variations of the conditioning factors of erosive processes. These models aim to: assist in agricultural planning, application of conservation techniques that reduce these losses as much as possible, minimization of environmental and economic damage, and improving soil quality (Amorim et al., 2010).

The most widely used indirect prediction model in soil science has been the K-factor of the Universal Soil Loss Equation (USLE), which expresses the soil's susceptibility to water erosion, capable of estimating soil losses from water erosion by throughout the year. The K factor is important in estimating erosion losses, which is characterized by being a procedure for combining soil characteristics, which allows its assessment through the USLE (Marques et al., 1997; Sá et al., 2004).

Properly managed pasture systems improve soil properties, such as: water retention, aggregate stability, soil organic matter content and nutrient cycling (Franzluebbers et al., 2011). Soares et al. (2016) also found that pasture areas have high percentages of aggregates with larger diameters.

Several studies have applied multivariate statistics to investigations of soil variables in pasture areas (Soares et al., 2016; Assunção et al., 2019; Dias et al., 2019; Zenero et al., 2019). According to Sena et al. (2002), one of the advantages of this technique is the formation of groups of populations with similar characteristics, allowing a better understanding of the variations of the processes that occur in the soil.

Thus, analyzing the spatial variability of the soil, geostatistics has been used as a tool that allows the interpretation and projection of results based on the structure of its natural variability. In addition, it facilitates the understanding of the variability of properties, and of their influence on production, showing the best management alternatives (Silva Neto et al., 2012).Thus, the study aimed to estimate the soil erodibility and its spatial variation using geostatistical techniques in pasture and forest areas in the municipality of Porto Velho-Rondônia.

2 I MATERIAL AND METHODS

2.1 Location and characterization

The study was carried out in the União Bandeirante district located in the city of Porto Velho, Rondônia, Brazil. The geographical coordinates are latitude 9º 45 '32' 'S and longitude 64º 31' 39 '' W (Figure 1), which represent three areas, two areas with pastures – brachiaria (*Brachiaria brizantha* cv. Marandu) and mombaça (*Panicum maximum* cv. Mombaça); and an area with native forest.

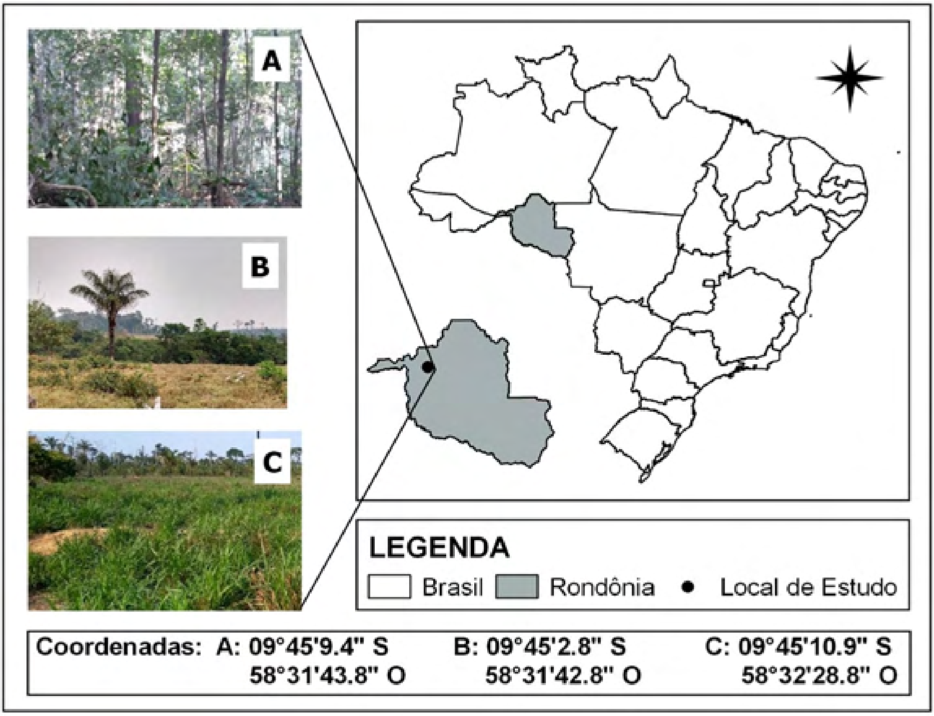

Figure 1. Location map of the study area: A: Forest, B: Brachiaria (*Brachiaria brizantha* cv. Marandu) and C: Mombaça (*Panicum maximum* cv. Mombaça), in the municipality of Porto Velho, RO.

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

The soils found are developed from undifferentiated sedimentary covers, associated with environments of alluvial fans, fluvial channels, flood plains and lakes, constituted by sediments whose granulometry varies from gravel to clay, with significant lateritization (Adamy, 2010).

The predominant soils in Rondônia are the Latossolos, which occupy an area of around 58%, being 26% of the Latossolo Vermelho Amarelo, 16% of the Latossolo Vermelho and 16% of the Latossolo Amarelo. Argissolos and Neossolos occupy 11% of the territory each, Cambissolos occupy 10% and Gleissolos occupy 9%.The other soil classes occupy the rest of the area (12%) (Schlindwein et al., 2012).The vegetation typology is called Dense

Ombrophilous Forest (IBGE, 2004), composed of dense and multilayered trees between 25 and 30 meters high (Perigolo et al., 2017).

For implantation of pasture areas, deforestation was carried out with successive burningover time, aiming to facilitate the cleaning of areas for later sowing of forages. Altogether there are 110 animals raised in the area with a size of 44.28 ha. These animals are rotated every 45 days between paddocks with brachiaria and mombaça grass, using a paddock for each grazing area.

The area with brachiaria has 26.36 ha, was implanted in 2008, remained unused for one year and was used infrequently until 2010, after which 4.5 animals/ha were used. The area with mombaça grass has 17.92 ha, was introduced in 2007, was left unused for three years, after which 6.14 animals/ha were used in the 45-day rotation between the brachiaria.

2.2 Field methodology

In the field, a 90 m x 60 m mesh was established for both areas with brachiaria and mombaça grass, and 90 m x 50 m for the forest area, with a regular spacing of 10 m between the sampling points for both areas. The crossing points of the meshes were georeferenced with a GPS equipment (DATUM WGS 84) for the construction of the Digital Elevation Model (DEM). In each collection area, an altimetric survey was carried out (Figure 2).

The soil was collected at the crossing points of the meshes, at a depth of 0.0-0.2 m, composing 60 sample points for the forest area and 70 points for each pasture area, totalizing 200 samples. For each area we collect soil clods with 10 cm high. These samples were used to determine the organic carbon and the physical properties of the soil.

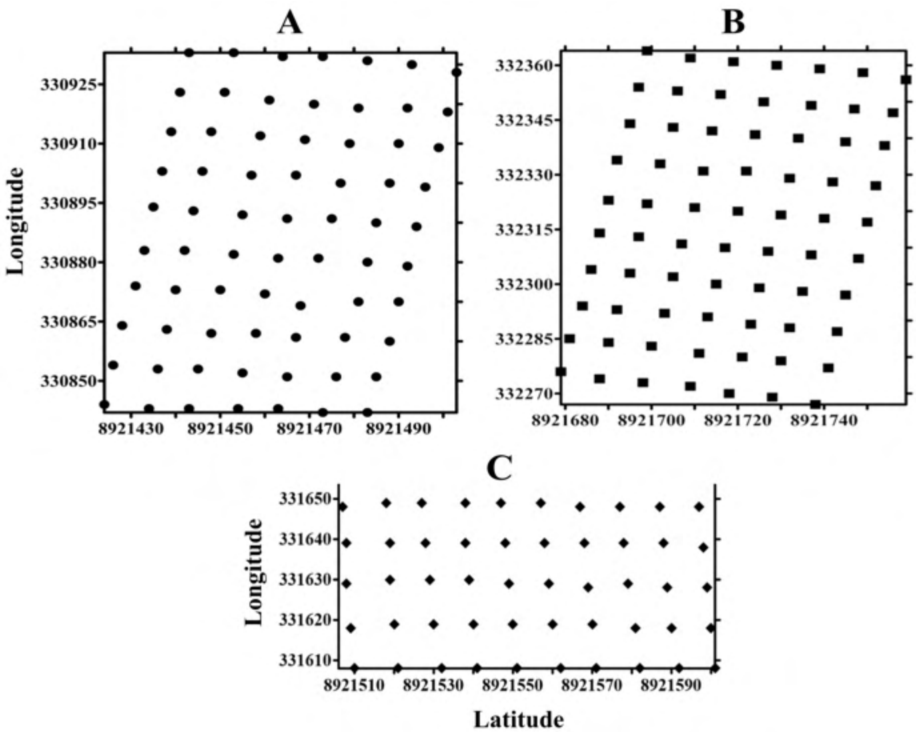

Figure 2. Meshes of the study area: A: Forest, B: Brachiaria (*Brachiaria brizantha* cv. Marandu) and C: Mombaça (*Panicum maximum* cv. Mombaça), in the municipality of Porto Velho, RO.

2.3 Laboratory metodhology

The collected soil underwent a process of natural drying and breaking, then it was sieved in a 2 mm mesh, composing the Air-Dried Fine Earth (ADFE) necessary for the analysis of organic carbon (OC) and particle size (sand, silt and clay) following the methodology proposed by Teixeira et al. (2017).

Textural analysis of the soil was determined using the pipette method, with NaOH solution 1 mol L^{-1} as a chemical dispersant and mechanical agitation using the Wagner type agitator, in a slow rotation apparatus for 16 hours at 50 rpm.

The granulometric fractions of the sand obtained from the texture were sieved to determine the dimensions of its solid particles. Each sample was shaken for 3 minutes using a sieve pattern with the following meshes: 2 mm, 1 mm, 0.5 mm, 0.250 mm, 0.125 mm and 0.053 mm. For this fractionation of the sand, a Sieve Agitator (Teixeira et al., 2017) model SOLOTEST was used, necessary to estimate the erodibility factors.

Organic carbon (OC) was determined by the Walkley-Black method (1934), modified by Yeomans & Bremner (1988), in which the OC is oxidized with a mixture of potassium dichromate 0.0667 mol L^{-1} and titrated with ammoniacal ferrous sulphate 0.102 mol L-1in the presence of the diphenylamine indicator (1%) (Teixeira et al., 2017).Considering that the OC contributes around 58% in the composition of the humus, the organic matter (OM) of the soil was estimated by the expression: OM = OC x 1.724.

2.4 Calculation of erodibility factors (k, ki, Kr) AND SHEAR STRESS (τ_c)

To estimate soil erodibility, indirect prediction models were used, which involve the values of soil attributes analyzed in the laboratory. Thus, in the present work, the USLE (Universal Soil Loss Equation) and the WEPP (Water Erosion Prediction Project) models were used to determine the conditioning factors of erosion in the study sites.

To calculate the global soil erodibility (K factor, t ha-1 MJ^{-1} mm^{-1} ha^{-1} h), the methodmodified by Denardin (1990) was used to evaluate K factor in Brazilian soils, according to Equation 1.

$$K = 0.00000748M + 0.00448059p - 0.0631175X_{27} + X_{32} \quad (1)$$

where:

M =new silt x (new silt + new sand);

p =permeability coded according to Wischmeier et al. (1971);

X27 = [(0.002 x clay, %) + (0.026 x silt, %) + (0.075 x very fine sand, %) + (0.175 xfine sand, %) + (0.375 x medium sand, %) + (0.75 x coarse sand, %) + (1.5 x very coarse sand, %)] / (clay, % + silt, % + sand, %);

X32 = newsand x (OM/100);

New silt = silt + very fine sand, %;

New sand =very coarse sand + coarse sand + medium sand + fine sand, %.

To calculate the interrill erodibility (Ki, kg s m^{-4}), rill erodibility (Kr, s m^{-1}), and the critical shear stress (τ_c, N m^{-2}), we use equations from the WEPP model proposed by Flanagan & Livingston (1995) (Eq. 2, 3, 4, 5, 6 and 7).

$$K_{iwepp} = 2728000 + 192100\,VFS \qquad \text{sand} \geq 30\% \quad (2)$$
$$K_{iwepp} = 6054000 - 55130\,CLAY \qquad \text{sand} < 30\% \quad (3)$$
$$K_{rwepp} = 0.00197 + 0.00030\,VF0S + 0.03863 \times e^{-1.84*OM} \qquad \text{sand} \geq 30\% \quad (4)$$
$$K_{rwepp} = 0.0069 + 0.134 \times e^{-0.20*CLAY} \qquad \text{sand} < 30\% \quad (5)$$
$$T_{Cwepp} = 2.67 + 0.065\,CLAY - 0.058\,VFS \qquad \text{sand} \geq 30\% \quad (6)$$
$$T_{Cwepp} = 3.5 \qquad \text{sand} < 30\% \quad (7)$$

where:

VFS =very fine sand, %;

CLAY = clay percentage;

OM =soil organic matter, %;

2.5 Statistical analysis

2.5.1 Univariate and descriptive statistics

After determining the texture, soil organic matter and erodibility factors, univariate statistics (ANOVA) were performed to compare means of the attributes individually by the Tukey test ($p<0.05$).Both descriptive statistics and ANOVA were performed using the SPSS 21.0 software (SPSS Inc., 2017), in which the values of mean, median, standard deviation, coefficient of variation, asymmetry and kurtosis were calculated. The hypotheses of normality of the data were verified by the Kolmogorov-Smirnov test, using the statistical software Statistica 7.0 (Statsoft, 2004).

The coefficient of variation (CV%) was assessed according to the classification proposed by Warrick & Nielsen (1980), which classifies soil variables as: CV <12%, 12 <CV <60%, and CV> 60% for low, medium and high variability, respectively.

2.5.2 Multivariate analysis

For multivariate analyzes (MANOVA), a factor analysis extracted by the method of Principal Component Analysis (PCA) was performed to obtain a set of smaller linear combinations of soil attributes that preserve most of the data provided by the soil property (Silva et al., 2010). The PCA aimed to find statistical significance of the sets of soil attributes that most discriminate the environments under study, obtaining as an answer in which environments the attributes are more influenced by the anthropic action. In this way, the PC allowed to evaluate at the same time qualitatively the interactions between soil attributes, by standardizing the values of the attributes to mean equal to zero and variance equal to one.

The adequacy of the factor analysis was indicated by the Kaiser-Meyer-Olkin (KMO) measure, which assesses the simple and partial correlations of the variables, and by the Bartlett sphericity test, which accepts or rejects the equality between the correlation and identity matrices. The extraction of the factors was performed by the principal component analysis, incorporating the variables that presented commonality equal to or greater than five (5.0), as described by Mingoti (2007).However, the choice of the number of factors to be used was made by the Kaiser criterion (factors that have eigenvalues greater than 1.0), so that they reach an accumulated variance above 70% of the variance of the variables. In order to simplify the factor analysis, orthogonal rotation (varimax) was performed and represented in a factorial plane of the variables for the principal components (Burak et al., 2010).

2.5.3 Geostatistical analysis

Geostatistics was used to assess the spatial variability of the analyzed attributes. For this, it was necessary to know if there is spatial dependence or not on the attributes studied, verified through the graph of the semivariograma. The GS+ 7.0 software (Robertson, 2004) was used to adjust semivariograms, based on the presupposition of stationary intrinsic hypothesis (Eq. 8).

$$\hat{\gamma}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z(x_i) - Z(x_i + h) \right]^2 \quad (8)$$

where:

γ (h)=semivariance value for a distance *h*;

N (h)=number of pairs involved in calculating the semivariance;

Z (x_i)=value of attribute *Z* in position x_i;

Z (x_i + h)=value of attribute *Z* separated by a distance *h* from position x_i.

During the adjustment, the coefficients of determination (R²) and cross-validation (C-V) served as the basis for choosing the best theoretical model for the semivariogram.From the choice of the model type (linear, spherical, gaussian, exponential), its parameters were defined (nugget effect –C_0, sill –C_0+C, and range –*a*).

To analyze the Degree of Spatial Dependence (DSD) of the attributes that presented a spatial dependence structure, the examination of the parameters of the semivariograms proposed by Cambardella et al. (1994) was used. Thus, the semivariograms that have: DSD ≤ 25%, 25% <DSD<75%, and DSD > 75% are considered as having strong, moderate and weak spatial dependence, respectively.

After geostatistical modeling, the data generated were interpolated using kriging in the Surfer software version 13.0 (Golden Software Inc., 1999).Then, the individual semivariograms were scaled for all variables in each area studied, with the aim of reducing them to the same scale, facilitating the comparisonof results from different areas (Ceddia et al., 2009).

The experimental semivariograms were scaled by dividing the semivariances by the statistical variance (Guimarães, 1993).Thus, the choice of the scaled semivariogram model that best fitted the data was performed based on the determination coefficient (R^2), cross-validation (C-V), in addition to the practical knowledge of the behavior of the attributes in the environments.

3 | RESULTS

Evaluating the dispersion of the variables (Table 1), it was observed in the pasture areas (brachiaria and mombaça) in comparison with the forest area, that the measures of central tendency (mean and median) of the variables presented symmetrical distribution, and both showed values very close for all attributes, which justifies normal or approximately normal distributions of the analyzed data.

It was noted through the texture results that the average values in the forest area indicate that this area has more clay, more organic matter and higher values of K and τ_{cwepp} than in the areas with pastures.

Thus, the asymmetry values ranged from -0.45 to 1.02, where variables with values greater than zero represent data with an asymmetric distribution on the right while the negatives indicate that they have an asymmetric distribution on the left. For kurtosis, values from -0.03 to 1.92 were observed, these values should preferably be null, however values between -2 to +2 are acceptable (Negreiros Neto et al., 2014).

In the mombaça grass area, it was found that the standard deviation values were high, highlighting the value of 6.30 $g.kg^{-1}$ for organic matter (OM). For the forest area, the OM presented a standard deviation value equal to 4.85 $g.kg^{-1}$ and the lowest value found for the brachiaria area (3.93 $g.kg^{-1}$).

Through the classification of the variation coefficient (CV%) proposed by Warrick & Nielsen (1980), it was found that the highest value was found in the forest area (33.27%), followed by the mombaça grass area (30.55 %) and brachiaria (30.07%,), all for the variable silt, being classified as medium variability of the data. The variable with the least variability was sand with a value of 3.95% in the brachiaria area.

In general, the K factor for all areas showed normal hypothetical data distribution using the Kolmogorov-Smirnov test at 5% probability. Thus, the erodibility factors K, K_{iwepp} and τ_{cwepp} showed low variability for the forest area, indicating a good homogeneity of the area, in addition to a good representativeness of the samplings performed.

However, the K factor (t ha^{-1} MJ^{-1} mm^{-1} ha h) was lower in the brachiaria area (0.01), and a higher value was observed in the forest area (0.03), as Table 1. Thus, the high value in the forest area may be related to the high content of OM present, which does not match the types of soils for which USLE was developed and adapted

Properties	Mean	Median	Asymmetry	Kurtosis	[1]S.D.	[2]CV%	[3]K-S
				Native Forest area			
Sand (%)	50.67**c**	50.85	-0.03	-0.93	2.55	5.03	0.08*
Silt (%)	5.66**a**	5.70	-0.06	-0.90	1.88	33.27	0.08*
Clay (%)	42.68**a**	42.74	-0.14	-0.69	3.00	7.03	0.09*
[4]OM ($g.kg^{-1}$)	36.10**a**	35.46	0.55	0.21	4.85	13.43	0.06*
[5]Factor K	0.03**a**	0.03	0.13	-0.48	0.00	8.65	0.08*
[6]K_{iwepp}	$3.42E^6$**b**	$3.38E^6$	0.17	-1.35	$2.08E^5$	6.08	0.13*
[7]K_{rwepp}	0.0032**b**	0.00	0.11	-1.24	0.00	10.66	0.13*
[8] τ_{cwepp}	5.29**a**	5.28	0.07	-0.61	0.23	4.27	0.06*
				Brachiaria area			
Sand (%)	66.83**a**	67.24	-0.24	-1.06	2.64	3.95	0.10*
Silt (%)	2.95**c**	2.86	0.18	-0.90	0.89	30.07	0.06*
Clay (%)	30.11**a**	29.92	0.12	-0.96	2.53	8.41	0.09*
[4]OM ($g.kg^{-1}$)	25.65**b**	25.85	-0.01	-0.55	3.93	15.33	0.05*
[5]Factor K	0.01**c**	0.02	0.45	-0.14	0.00	13.56	0.09*
[6]K_{iwepp}	$3.80E^6$**a**	$3.81E^6$	0.02	-1.39	$3.51E^5$	9.23	0.13*
[7]K_{rwepp}	0.0042**a**	0.00	0.00	-1.00	0.00	15.83	0.08*
[8] τ_{cwepp}	4.32**c**	4.30	0.36	-0.53	0.22	4.99	0.07*
				Mombaça area			
Sand (%)	56.28**b**	56.65	-0.45	0.57	3.61	6.41	0.13*
Silt (%)	4.45**b**	4.48	0.62	0.31	1.36	30.55	0.10*
Clay (%)	39.27**b**	38.83	0.62	0.30	3.53	9.00	0.13*
[4]OM ($g.kg^{-1}$)	28.43**b**	27.23	1.02	1.44	6.30	22.16	0.12*
[5]Factor K	0.02**b**	0.02	0.80	1.53	0.00	15.18	0.07*
[6]K_{iwepp}	$3.23E^6$**c**	$3.19E^6$	0.35	-0.68	$2.34E^5$	7.26	0.07*
[7]K_{rwepp}	0.0031**b**	0.00	0.90	1.92	0.00	16.90	0.09*
[8]τ_{cwepp}	5.07**b**	5.02	0.60	-0.03	0.26	5.11	0.10*

Means followed by equal letters in the column do not differ by Tukey's test at the 5% probability level. [1]S.D.: standard deviation; [2]CV%: coefficient of variation,%; [3]K-S: normality test (Kolmogorov-Smirnov significant at 5% probability); [4]OM: organic matter; [5]K: soil erodibility, $t.ha^{-1}.MJ^{-1}.mm^{-1}.ha.h$; [6]$K_{iwepp}$: interrill erodibility, $kg.s.m^{-4}$; [7]K_{rwepp}: rill erodibility, $kg.N^{-1}.s^{-1}$; [8]τ_{cwepp}: critical shear stress, $N.m^{-2}$.

Table 1.Descriptive statistics of texture, organic matter and soil erodibility factors in pasture and forest areas in the city of Porto Velho, RO.

Table 2 shows the parameters of the adjusted semivariograms that best describe the spatial distribution of the analyzed attributes. It was confirmed that in the forest area, the attributes have a spatial dependence structure with a moderate degree for sand (27.70%) and with a strong spatial dependence for all other attributes (DSD<25%). Some variables showed a condition of pure nugget effect (PNE), such as the factor $K_{i\ wepp}$ (interrill erodibility) and $K_{r\ wepp}$ (rill erodibility), that is, they did not show a spatial dependence structure.

On the other hand, in the brachiaria area the variable τ_{cwepp} showed moderate spatial dependence with a value of 28.10% and the other variables a strong spatial dependence (DSD<25%). In the mombaça area, it is observed that the variables sand, clay and organic matter showed strong DSD, with moderate DSD for the other variables, showing that possibly the mombaça grass area is more influenced by the intrinsic properties of the soil linked to the formation factors (Cambardella et al., 1994).

Attribute	Forest						Brachiaria						Mombaça					
	Mod.	C_0	C_0+C_1	a (m)	R^2	DSD%	Mod.	C_0	C_0+C_1	a (m)	R^2	DSD%	Mod.	C_0	C_0+C_1	a (m)	R^2	DSD%
Sand	Exp.	3.68	13.28	79.29	0.92	27.70	Gau.	2.31	18. 94	89.21	0.98	12.20	Exp.	1.85	16.02	72.00	0.81	11.50
Silt	Exp.	0.83	6.18	25.20	0.85	13.40	Lin.	-	-	-	-	PNE	Exp.	0.46	1.30	27.60	0.81	35.50
Clay	Exp.	0.01	14.51	40.50	0.90	0.10	Exp.	0.10	14.89	90.00	0.90	0.70	Exp.	2.52	17.26	90.00	0.90	14.60
OM	Sph.	0.02	32.54	22.80	0.80	0.60	Sph.	0.01	15.03	20.69	0.71	0.00	Sph.	7.52	30.07	17.60	0.71	25.00
KFactor	Exp.	0.00	0.00	32.40	0.77	0.00	Exp.	0.00	0.00	39.90	0.71	0.00	Exp.	0.00	0.00	27.84	0.70	37.50
$K_{i\ wepp}$	Lin.	-	-	-	-	PNE	Lin.	-	-	-	-	PNE	Lin.	-	-	-	-	PNE
$K_{r\ wepp}$	Lin.	-	-	-	-	PNE	Lin.	-	-	-	-	PNE	Lin.	-	-	-	-	PNE
$\tau_{c\ wepp}$	Exp.	0.01	0.08	48.00	0.81	15.40	Exp.	0.03	0.03	86.78	0.95	28.10	Exp.	0.02	0.08	86.40	0.86	28.40

Mod.: Model; Sph.: Spherical; Exp.: Exponential; Lin.: Linear; Gau.: Gaussian; C_0: Nugget effect; C_0+C_1: Sill; a: Range; R²: Coefficient of determination; DSD%: Degree of Spatial Dependence; OM: Organic Matter; PNE: Pure NuggetEffect; K: Erodibility of the soil; K_{iwepp}: interrill erodibility; K_{rwepp}: rill erodibility; τ_{cwepp}: critical shear stress.

Table 2.Models and parameters estimated to semivariograms, under 0.0-0.2 m layer, in forest and pasture areas in the municipality of Porto Velho, RO.

The adjustments of the experimental semivariograms, kriging maps and spatial dependence analysis are shown in Figures 4, 5, 6, 7, 8 and 9, for the forest, brachiaria and mombaça grass areas.

Through the results it was possible to observe that the attributes showed spatial dependence, adjusting predominantly to the exponential and spherical models with values of R^2 above 0.70 for all areas.

Oliveira et al. (2015a), studying soils in Amazonas, observed the predominance of the spherical model in forest area and exponential model in pastures to the adjustment of semivariograms for soil attributes.

The coefficient of determination showed values ranging from 0.71 to 0.98 while cross-validation varied from 0.71 to 1.00 for all areas. According to Azevedo (2004), the more the R^2 is close to 1.00, the better the estimation of the values by the common kriging method.

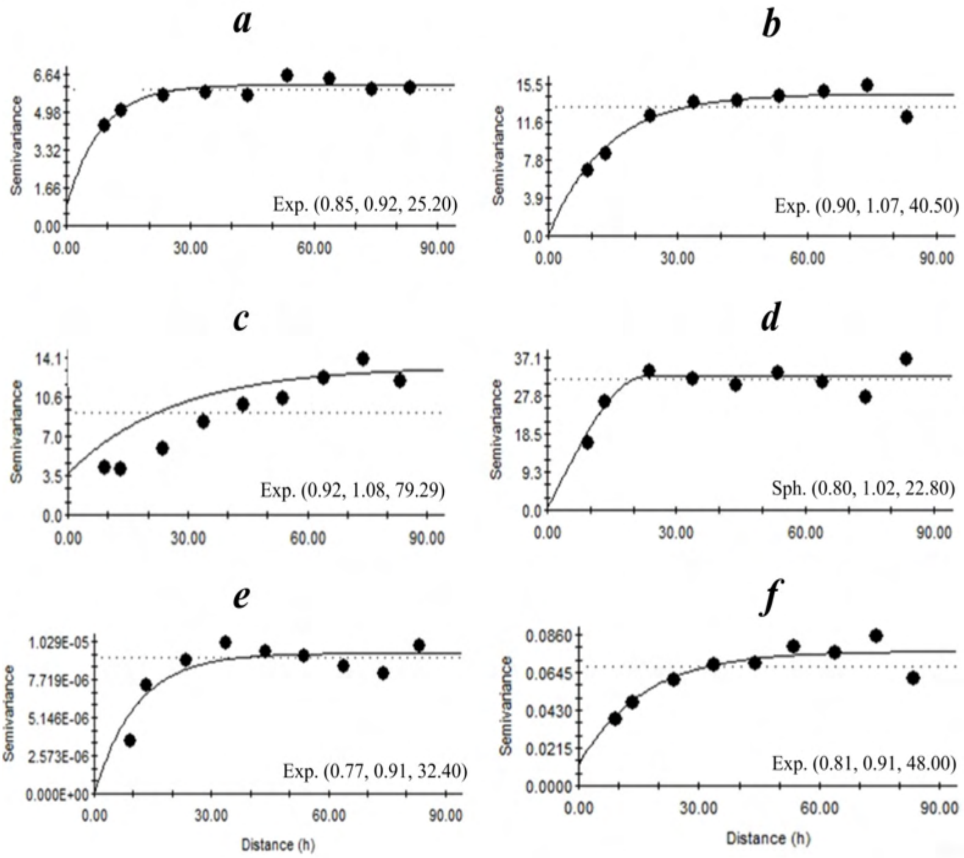

Figure 3. Experimental semivariograms adjusted for erodibility factors at a depth of 0.0-0.2 m, in a forest area in the municipality of Porto Velho, RO. The letters represent the attributes: silt (*a*), clay (*b*), sand (*c*), OM (*d*), K factor (*e*) and shear stress (*f*).The values in parentheses represent, respectively: coefficient of determination (R^2), cross-validation (C-V) and range (*a*).

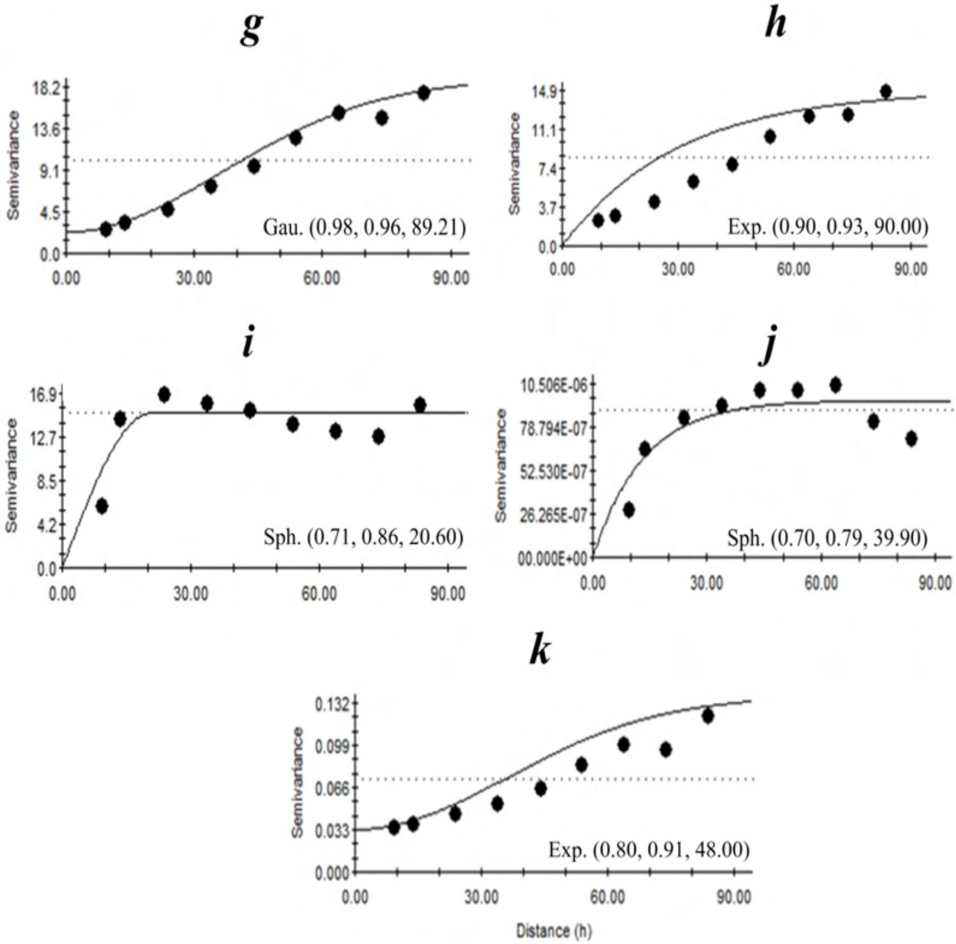

Figure 4. Experimental semivariograms adjusted for erodibility factors at a depth of 0.0-0.2 m, in a brachiaria area in the municipality of Porto Velho, RO. The letters represent the attributes: sand (*g*), clay (*h*), OM (*i*), K factor (*j*) and shear stress (*k*).The values in parentheses represent, respectively: coefficient of determination (R^2), cross-validation (C-V) and range (*a*).

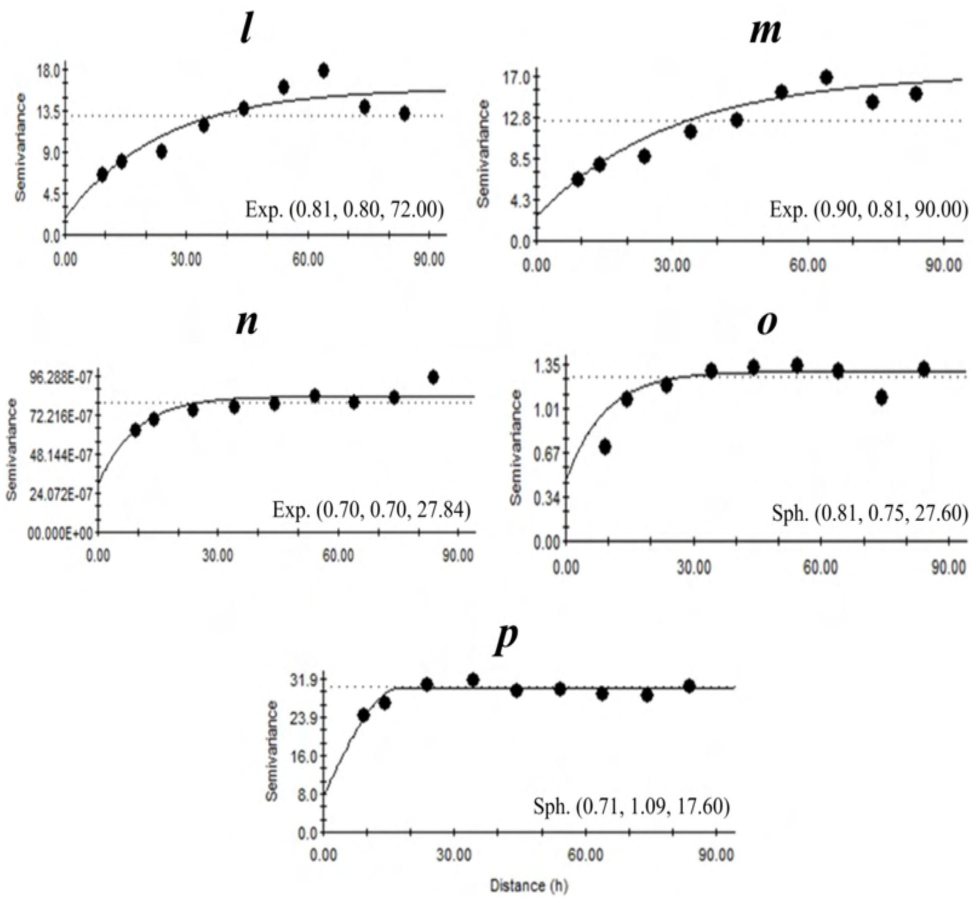

Figure 5. Experimental semivariograms adjusted for erodibility factors at a depth of 0.0-0.2 m, in a mombaça grass area in the municipality of Porto Velho, RO. The letters represent the attributes: sand (*l*), clay (*m*), K factor (*n*), silt (*o*), and OM (*p*).The values in parentheses represent, respectively: coefficient of determination (R^2), cross-validation (C-V) and range (*a*).

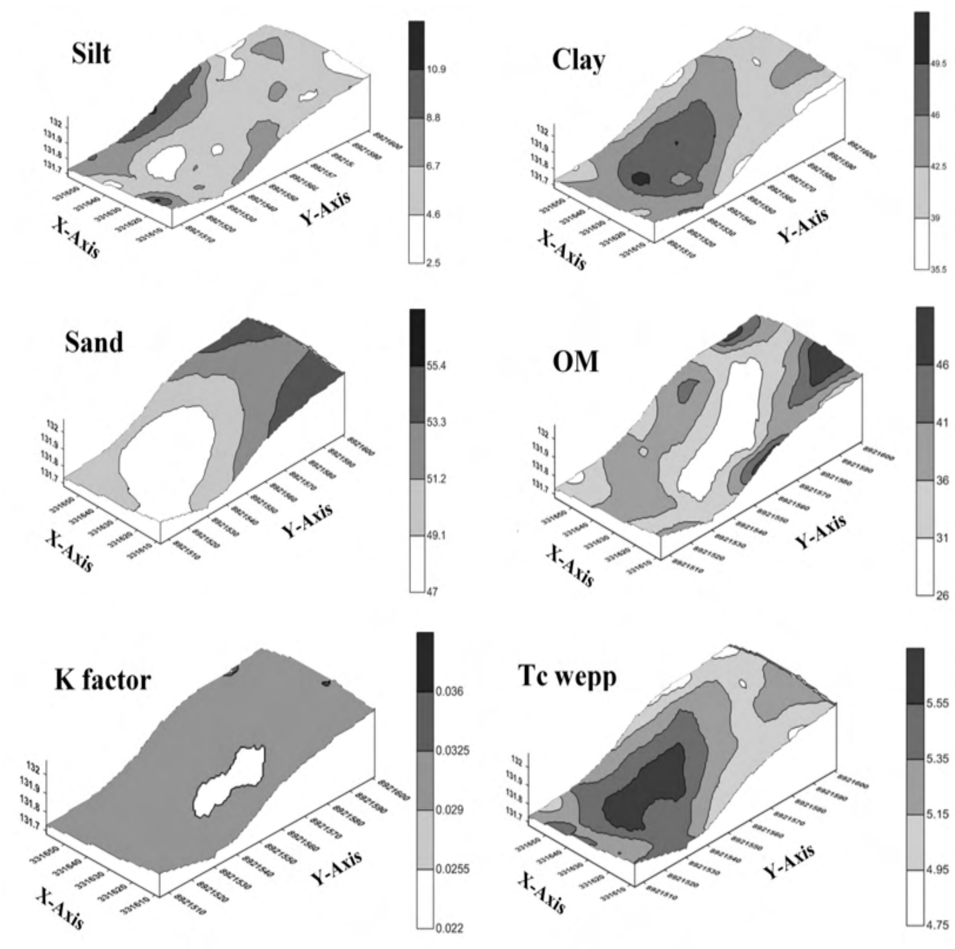

Figure 6. Kriging maps of soil attributes and erodibility factors in a native forest area in the municipality of Porto Velho, RO.

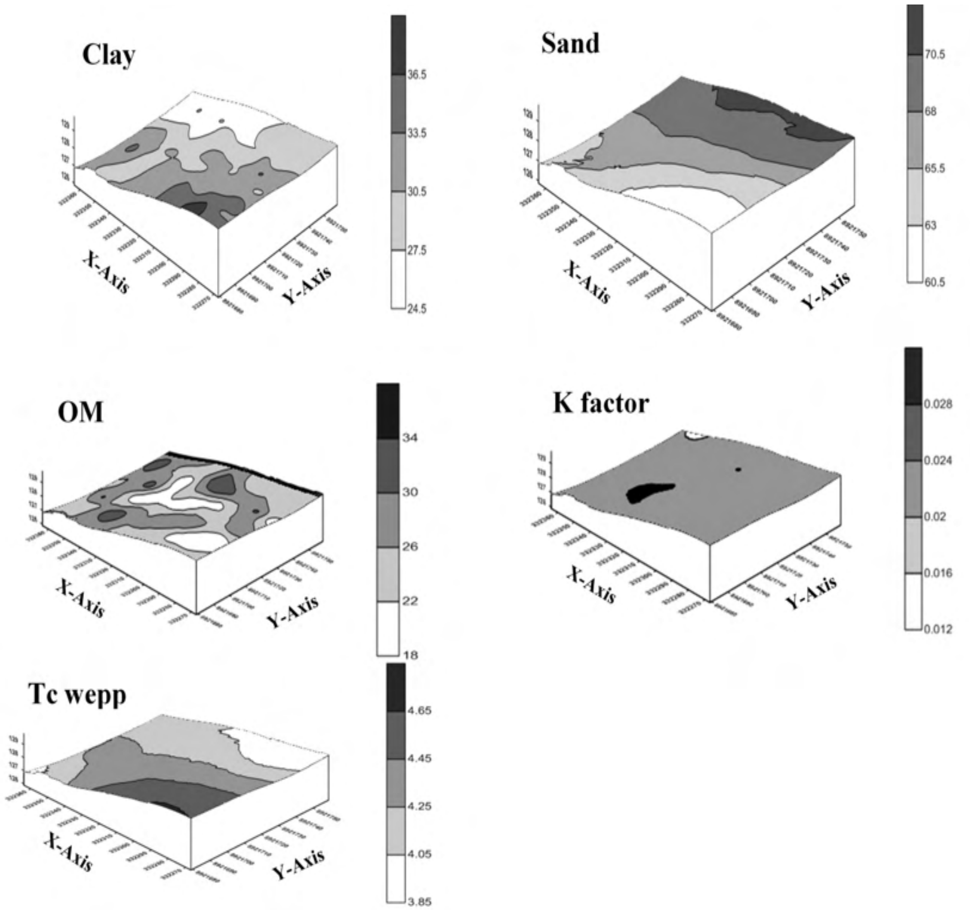

Figure 7. Kriging maps of soil attributes and erodibility factors in a brachiaria area in the municipality of Porto Velho, RO.

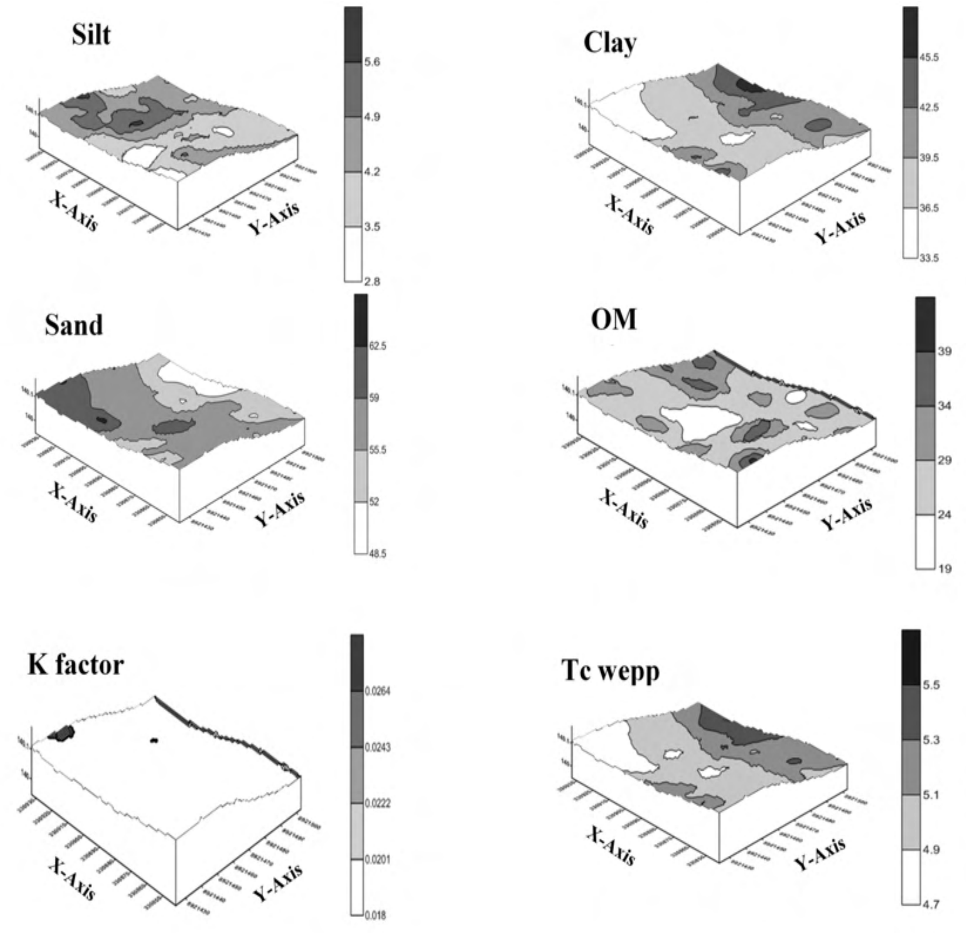

Figure 8. Kriging maps of soil attributes and erodibility factors in a mombaça area in the municipality of Porto Velho, RO.

The scaled semivariograms for the three areas studied are shown in Figure 9. The model adjusted to the graphs is exponential for the three areas, which showed R^2 performance between 0.57 to 0.69 and cross-validation between 0.76 to 0.83. Oliveira et al. (2015b) also observed that, in forest and pastures areas, the exponential model fits better for the chemical attributes of the soil.

The areas presented range values (a) ranging from 35.00 to 67.52 m, with the highest value being found for the brachiaria area and the lowest value in the native forest area. In relation to DSD%, the forest and brachiaria area showed variables with strong spatial dependence. In contrast, the mombaça grass area showed moderate spatial dependence (Cambardella et al., 1994).

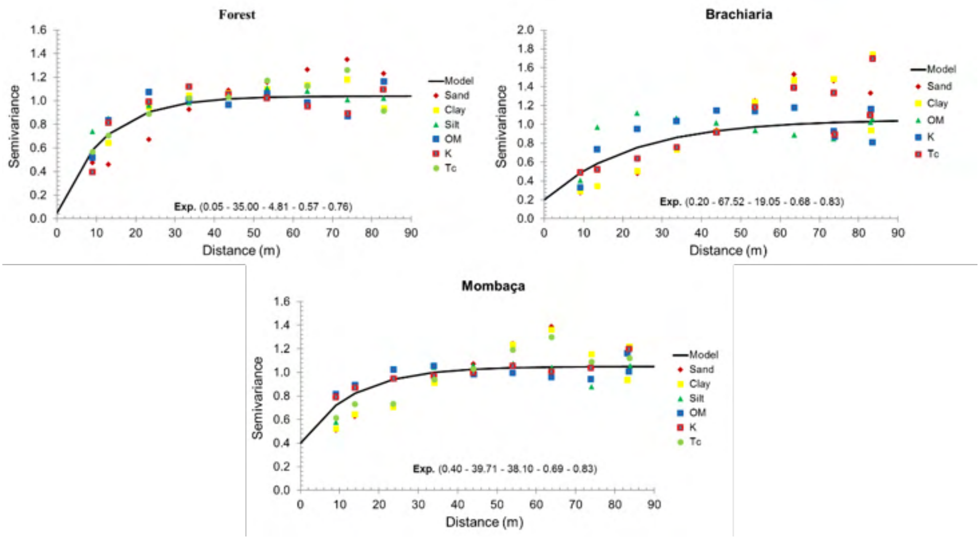

Figure 9. Scaled semivariograms for the environments studied in Porto Velho, Rondônia. The values in parentheses indicate respectively: nugget effect (C_0), range (*a*), Degree of Spatial Dependence (DSD%), coefficient of determination (R^2) and cross-validation (C-V).

The factor analysis showed significant results (KMO = 0.772; p <0.05, for the Barlettsphericity test) for the variables in the evaluated areas, showing suitability for the construction of the Principal Components (Figure 10).

In the principal component analysis (PCA), with the variables with the highest scores, two main components were extracted, which could explain the total variability of the data for the 0.0-0.2 m depth, in which the studied environments were influenced by the high levels of sand and clay, which interfere with soil compaction and OM accumulation (Table 3 and Figure 10).

However, each area had a well-distributed score distribution within the factorial plane, discriminating the specific characteristics presented by the type of management adopted in each studied area.

Attributes	Common Variation	Factors	
		PC1	PC2
Clay	0.89	0.77*	0.52
Sand	0.89	-0.73*	-0.56
OM	0.60	0.12	0.91*
K	0.67	0.22	0.90*
$K_{i\ wepp}$	0.34	-0.82*	-0.01
T_{cwepp}	0.42	0.78*	0.18
Explanatory Variance		61.26	18.24

*More discriminatory values; PC1: principal component 1; PC2: principal component 2.

Table 3.Correlation between each principal component with soil texture and erodibility.

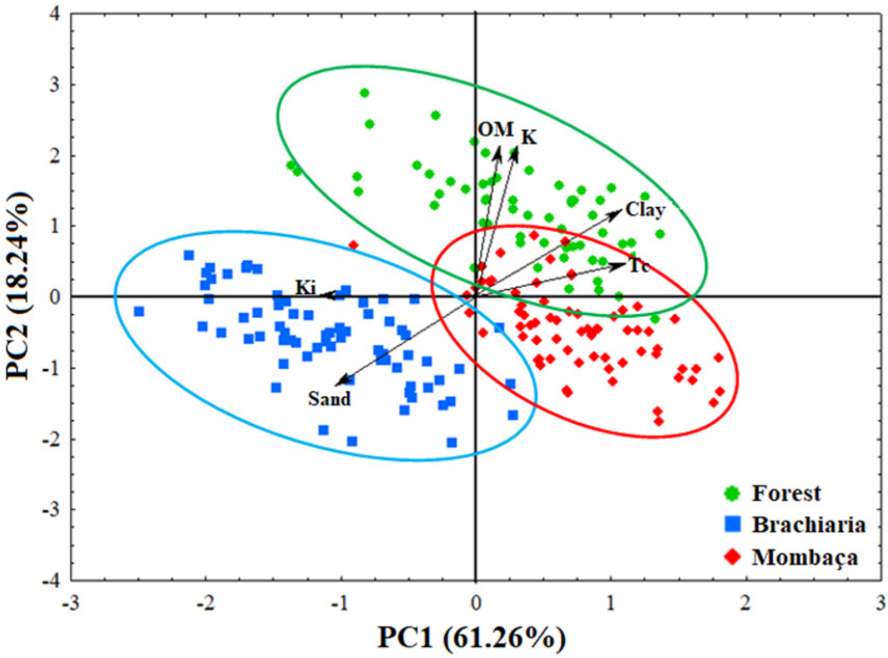

Figure 10. Principal component analysis of soil attributes at 0.0-0.2 m depth in pastures and forest areas in the municipality of Porto Velho, RO.

4 | DISCUSSIONS

Studies highlight that asymmetry and kurtosis are indicators of data distribution, however, they are more sensitive to extreme values than the mean and median, and such values close to zero indicate greater normality of the data (Kamimura et al., 2013; Alho et al., 2016), with symmetrical values or not, the ideal is that these values are close to the central zero value (Cortez et al., 2011). For kurtosis, values of - 0.03 to 1.92 were observed, these values should preferably be null, however values between -2 to +2 are acceptable (Negreiros Neto et al., 2014).

According to Oliveira et al. (2015), the statistical measure of CV% allows comparing the variability between samples of variables with different units, however it does not allow analyzing the spatial variability of soil attributes. Considering that the CV% indicates the variability of the data in relation to the mean, the smaller the value the more homogeneous the data set is, it is possible to evaluate the homogeneous condition for the results found in the present study.

According to Frogbrook et al. (2002), high values of CV% can be considered as the first indicators of the existence of heterogeneity in the data. Thus, based on the CV% values found, it was possible to state that the analyzed attributes presented low to medium variation for the studied areas, corroborating with the results found by Cunha et al. (2017).

In general, analyzing the results of factor K, it was observed that they were lower than the values of 5.21×10^{-2} t ha^{-1} MJ^{-1} mm^{-1} ha h, found by Nunes et al. (2017) studying the application of the universal equation of soil losses in Argissolos in the southern region of Amazonas.

According to Castro et al. (2011), the K factor, can be classified into classes according to its potential, so that the authors adopt the following classifications: $K < 9.00 \times 10^{-3}$ (very low); $9.00 \times 10^{-3} < K \leq 1.50 \times 10^{-2}$ (low); $1.50 \times 10^{-2} < K \leq 3.00 \times 10^{-2}$ (mean); $3.00 \times 10^{-2} < K \leq 4.50 \times 10^{-2}$ (high); $4.50 \times 10^{-2} < K \leq 6.00 \times 10^{-2}$ (very high), and $K > 6.00 \times 10^{-2}$ (extremely high).

In this sense, taking into account that values found in the three areas studied ranged from 0.01 to 0.03t ha^{-1} MJ^{-1} mm^{-1} ha, it was possible to classify the areas in the following classes: low erodibility for the brachiaria area; and medium erodibility for mombaça grass and forest.

However, the forest area is located in areas considered to be flatter, allowing less conditions for sediment losses caused by water erosion, since it is the main form of degradation of Brazilian soils, caused by rain drops and runoff, which carry suspended soil particles, nutrients, organic matter and chemicals, causing serious damage to agricultural activities (Bertol et al., 2007).

Regarding $K_{i\ wepp}$ and $K_{r\ wepp}$, it was possible to observe that the brachiaria area had the highest value compared to the other areas studied, with a clear significant difference between them. In general, pasture areas, although well managed, are heterogeneous, and this problem can be even more accentuated when pastures are established in sloping areas (Artur et al., 2014).

When assessing the difference in texture for the three environments studied, it is observed that all areas at a depth of 0-0.2 m, showed a statistical difference (Table 1). When analyzing the fractions, it was observed that the sand fraction of the forest and pasture areas showed a significant difference between them by the Tukey test. The brachiaria area showed a medium texture, with high sand contents, while the forest and mombaça grass areas showed to be clayey. The high levels of sand in the brachiaria area may be related to the topography of the respective areas, due to the flood of small particles of the mineral fraction (clay) and organic matter, which are transported by surface runoff. In general, studies highlight that the topography of the terrain has a strong influence on erosion losses, especially due to the degree of slope and the length of the ramp (Campos et al., 2008).

Range (*a*) is a parameter of geostatistics that has served as a basis for sample planning, indicating the maximum distance at which the attribute is spatially correlated (Dalchiavon et al., 2012).Reflecting the degree of homogenization between the samples, the higher the value, the more homogeneous the phenomenon or process will be studied. Range values ranging from 22.80 (OM) to 79.29 m (sand) were observed, followed by brachiaria from 20.69 (OM) to 90.00 m (clay) and for mombaça grass 17.60 (OM) at 90.00 m (clay). This means that all neighbors within this radius can be used to estimate values in closer spacing, and that all samples are correlated and dependent on each other at the same distance from each other.

The area with brachiaria showed higher values of range in relation to the other areas, indicating that the area of brachiaria has less variability and is more homogeneous. In contrast, the area with mombaça grass showed smaller values of range, indicating that this area has greater variability, thus being more heterogeneous. Thus, this greater variability in the area of mombaça grass may be related to the greater grazing intensity (Alencar et al., 2016).

The Degree of Spatial Dependence (DSD) presented values varying from 0.00 to 37.50% between the studied areas, presenting strong spatial dependence (DSD<25%) and moderate (26% < DSD < 75%) (Cambardella et al., 1994), indicating that the studied variables are not randomly distributed in space (Cavalcante et al., 2011).

The mombaçagrass area showed a strong DSD for most of the variables compared to the variables of the forest and brachiaria environments, showing that possibly the mombaçagrass area is more influenced by the intrinsic properties of the soil linked to the formation factors (Cambardella et al., 1994).

However, the sand fraction of the forest area and the variable $\tau_{c\ wepp}$ for brachiaria area, alongwith the variables silt, K and $\tau_{c\ wepp}$ for mombaça grass, showed to have a moderate spatial dependence (26% < DSD < 75%). For the other variables, a strong degree of spatial dependence was found.

The semivariograms were adjusted to the exponential model for all areas studied except for the attribute OM, which presented the spherical model for brachiaria, mombaça and forest area (Figures 4, 5 and 6), and for the sand of the brachiaria area which best fit the Gaussian model (Figure 5). The choice of models was evaluated using the highest R^2 value, corroborating with Faraco et al. (2008), in which they evaluated the exponential model for most variables, followed by the spherical and Gaussian model and excluding those that presented a pure nugget effect (PNE).

According to Isaaks& Srivastava (1989), spherical models describe soil properties with high spatial continuity, that is, less erratic over short distances. Studies by Aquino et al. (2015), evaluating forest and pasture areas, observed that the spherical and exponential model were also the ones that best fit for physical soil attributes.

Carvalho et al. (2010) in a study about spatial variability of the physical and chemical attributes of the soil, mention that the R^2 and cross-validation are tools designed to evaluate alternative models of semivariograms that will perform kriging to predict values in places unsampled and to optimize sampling loops. The lowest values of the R^2 obtained were found in factor K and OM in the three areas. But in general the values were high, allowing to obtain maps of the spatial distribution of the attributes with quality.

Kriging maps allow the establishment of land use and management criteria in isolation for each variable evaluated, making it possible to improve the use of the area, the nutrition of pastures (Alencar et al., 2016), decreased production costs and quick and certain decision making, enabling greater productivity and also the conservation of the environment through less use of pesticides, in addition to providing more detailed and useful records of the productive area (Santos et al., 2017).

The K factor kriging maps showed smaller and uniform scores, indicating that soil losses, in general, occur more uniformly. Thus, the maps of the spatial distribution of the physical attributes are presented in Figures 7, 8 and 9, which allowed a greater understanding of the distribution of the analyzed areas. In this way, the study of the spatial distribution of the physical properties of the soil can be used to select indicators of groundwater storage and flow potential (Alvarenga et al., 2012) and to identify degraded pasture regions (Grego et al., 2012).

Through maps it is possible to observe spatial correlations between attributes, mainly those related to compaction. In general, it is possible to verify which attributes are most influenced by the relief. It is observed that the variables related to the texture suffer more changes due to the relief, that is, this occurs due to the microreliefs present in the areas, which condition the different flows of water and the soil particles from the highest parts to the lowest with it(Oliveira et al., 2013).

Burak et al. (2012) proved that the higher the PCA scores, the greater their contribution to positive correlations between the variables that make up each factor. In contrast, the K factor had lower scores, so the lower the scores, the greater the contribution to negative correlations.

The forest area showed most of the positive scores, while the pasture areas showed the most negative. According to Ribas & Vieira (2011), the objective of principal component analysis (PCA) is achieved when a relatively small number of extracted components have the ability to explain most of the variability in the original data. It allows to evaluate at the same time qualitatively the interactions between the attributes of the soil. In general, these attribute values were normalized to the mean equal to zero (0) and the variance equal to one (1).

In detail, the first component explained 61.26% of the total variability of the data, such component presented a percentage of explanation for attributes more focused on soil granulometric characteristics such as: sand, clay, $K_{i\ wepp}$ and τ_{cwepp}. It was also observed that only clay, OM, K and τ_{cwepp} correlated positively (Table 3, Figure 10).

The mombaça grass area functions as an intermediate environment between the forest and the brachiaria, being closer to the forest environment (Figure 10). Thus, PC2 shows that brachiaria is discriminated by the highest sand content, and PC1 by $K_{i\ wepp}$. However, the area with mombaça grass showed intermediate levels in relation to the areas studied. In general, it was possible to attribute the highest levels of sand and the lowest levels of silt and clay in the pasture areas in relation to the forest, the greater intensity of removal of fine particles provided by the microreliefs, and according to Oliveira et al. (2013), also to the conditioning of water flows (Oliveira et al., 2013), which are intensified by the low ground cover provided by pastures (Santos et al., 2018).

The second PC had an explanation percentage of 18.24% of the data variability, with characteristics more related to the condition of OM and factor K of the soil, and both attributes showed a positive correlation (Table 3). However, studies that address the soil organic matter fractions and their direct link to the K factor are still needed to understand why these two variables have a direct dependence relationship. In general, both PC retained a percentage of the explained variance of 79.50% (Table 3 and Figure 10).

However, it was observed that all quadrants in each environment need differentiated management, more or less intensive, and thereby increase the efficiency of the use of natural resources, reducing the impact of agriculture on the environment and optimizing the economic costs for the agricultural system (Santos et al., 2017).Couto et al. (2016), evaluating through MANOVA different environments in the southwestern Amazon, observed that the pasture and forest environment do not differ statistically, corroborating the results found here. Oliveira et al. (2015b), evaluating soils under different uses in the southern region of Amazonas, also verified through multivariate analysis that forest and pasture environments do not differ from each other.

However, studies are needed in other regions, mainly in Rondônia, where there is a high livestock production, as it is still possible to increase production without deforesting the areas, only improving the productivity of soils with adequate management, aiming at improving economic, social and environmental aspects.

5 I CONCLUSIONS

The high spatial variability of physical attributes in the environment with mombaça grass is attributed to the greater intensity of grazing and animal trampling.

The forest area represents most of the positive scores obtained in the principal component analysis, while the pasture areas the majority of the negative scores, indicating that the OM in the forest is correlated with the acidity components, differently from the correlations found for the pastures.

The K factor presented low variability for pasture area compared to forest area, indicating a good homogeneity of the area in addition to a good representativeness of the samplings carried out.

The brachiaria area has higher values of $K_{i\ wepp}$ and $K_{r\ wepp}$, with significant differences between the other areas. However, the forest and pasture environments differed in terms of soil erodibility, where the area with mombaça grass was intermediate between brachiaria and forest.

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