IMPACTS OF NATIVE FOREST CONVERSION ON SOIL ERODIBILITY IN AREAS OF AMAZONIC SPECIES CULTIVATION

SOUZA, F. G.[1] – CAMPOS, M. C. C.[2*] – OLIVEIRA, E. S.[3] – LIMA, A. F. L.[3] – PINHEIRO, E. N.[3] – CUNHA, J. M.[3] – MARTINS, T. S.[2] – SILVA, D. M. P.[3] – OLIVEIRA, F. P.[2]

[1]*Department of Agricultural Engineering, Federal University of Roraima, Av. Cap. Ene Garcês, 2413 - Aeroporto, 69310-000 Boa Vista, Roraima, Brazil*

[2]*Department of Soils and Rural Engineering, Federal University of Paraiba (UFPB), Km 12 Rodovia, PB-079, 58397-000 Areia, Paraiba, Brazil*

[3]*Institute of Education Agriculture and Environment, Federal University of Amazonas, Rua 29 de Agosto, 786, 69800-000 Centro, Humaitá, Amazonas, Brazil*

**Corresponding author*
e-mail: mcesarsolos@gmail.com; phone: +55-839-9885-7791

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Abstract. In Brazil, there are still relatively few studies involving soil erodibility, especially in areas that have undergone native forest conversion processes in agricultural areas. The objective of the present work was evaluate the impacts of native forest conversion on soil erodibility under conversion of native forest in areas of cultivation with guarana, annatto and cupuaçu in Amazonas state. Meshes were established according to the size of the crop, followed by sampling at the crossing points, at a depth of 0.00-0.20 m, with 80 sample points in each area. At each sampling point, were collected sample with a structure preserved for determination of soil texture and organic carbon, for a total of 320 samples in the four evaluated areas. The estimation of erodibility stands out as an important tool in the adoption of soil management and conservation practices, anticipating possible impacts before a crop is implanted. The areas cultivated with guarana and annatto presented greater predisposition of the soil to rill erosion and interrill. The areas of cupuaçu and forest presented high silt values, that may enhance/contribute to erodibility. In contrast, they showed high values of critical shear strength, which indicates resistance.

Keywords: *Amazonian soils, agriculture, erosion, agroecosystems, land use*

Introduction

The soil erosion is considered to be the most harmful form of degradation and the main cause of unsustainability in the agriculture production systems in global scale (Demarchi et al., 2019). A fact that has contributed for this unsustainability is the substitution of forested areas for cultivated areas without the adoption of technical criteria, which has been causing big changes in the soil characteristics, making the soil susceptible to erosion and degradation (Silva et al., 2021).

Scientific studies showed magnitude of the Brazilian Amazon forest degradation after the process of conversion (Souza et al., 2020), as well as the impacts and alterations of biodiversity and the ecologic or ecosystemic services (Lima et al., 2022), as well as bringing alterations to the chemical, physical and biological attributes, having effects over the environmental quality of the area (Frozzi et al., 2020).

Erodibility (K factor) is one of the variables of the Universal Soil Loss Equation (USLE) which expresses, quantitatively, the susceptibility of the soil to hydric erosion. It also represents an important factor in the estimation of the soil losses via erosion,

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factor that is characterized by being an expression of the combination of soil attributes, which enable its estimation via equations (Taleshian Jeloudar et al., 2018). The erodibility value is volatile, due to the wide variety of soils with differentiated attributes, making it risky to estimate a value based solely on the soil classification (Huang et al., 2022).

Some authors have highlighted the use of geostatistics techniques as an important tool for the study of erosion processes, given its notorious spatial and temporal variability (Mendonça et al., 2018). This method specially has been reflecting the reality, in the case of soil erosion (Silva et al., 2021). This is appropriate in situations where the available data are comprised of related variables, as the information stems from a variable which is supported by other, reducing the margin of error, being angle to predict everything from the variables, being useful in the estimation of the soil erodibility, as it depends on many variables, such as the organic carbon content, soil texture and permeability (Jiang et al., 2020).

In this sense, few works have explored the study of the erosion attributes spatial variability. An attribute spatial variability analysis option is to ally the use of multivariate analysis techniques, as is seeks the dimensional reduction of number of variables, to geostatistics. The multivariable analysis such as the factorial in main components, are tools that allow the condensation of all the information contained in a certain number of original variables in smaller sets, named factors, whose linear combinations explain the maximum variability contained in the original variables. The goal of the current study was to evaluate the impacts in soil erodibility in the conversion process of native forest in cultivation areas with guarana, annatto, and cupuaçu in the South of Amazonas.

Materials and methods

Localization and characterization of study area

The study was developed in two rural proprieties which are part of the São Francisco Settlement, localized in the municipality of Canutama, Amazonas, Brazil, under the geographic coordinates of reference 8° 13’ 23” S; 64° 00’ 50” W and 8° 13’ 25” S; 64° 00’ 23” W, for both proprieties. Four areas were selected, with three areas under different cultivations: Annatto (*Bixa orellana* L.), Cupuaçu (*Theobroma grandiflorum* (Willd. ex. Spreng) Schum), Guarana (*Paullinia cupana* (Mart.) Ducke) and the forest area (*Fig. 1*).

The soil of the study area were classified according to criteria established by the Brazilian Soil Classification System (Santos et al.,, 2018) as Argissolo Vermelho-Amarelo Distrófico and the World Reference Base of Soils (IUSS Working Group WRB, 2022) as Chromic Abruptic Acrisol, located in the Amazon Plains between the Purus and Madeira rivers, also associated to recent and old alluvial deposits, of the Quaternary period, characterized by the presence of tabular geography of great dimensions, defined by talwegs of very weak deepening, that is, the embossed terrain displays very smooth slopes, and the natural drainage is deficient (Campos et al., 2012). In regards to the climatic characterization, the region’s climate is Rainy Tropical, displaying a dry period of short duration. The partial average rainfall ranges from 2250 and 2750 mm per year, with a rainy period between October and June. The average annual temperatures range from 25 to 27 °C and the relative humidity of the air between 85 and 90% (Alvares et al., 2013).

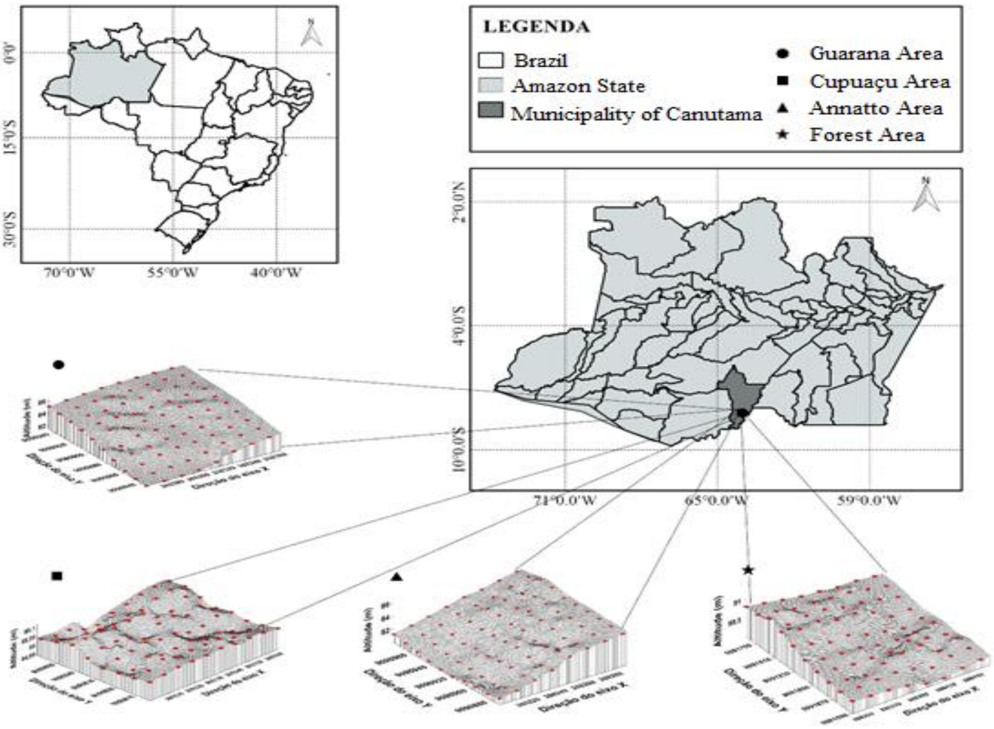

Figure 1. *Localization and model of digital elevation of the areas with guarana, cupuaçu, annatto and forest, in the municipality of Canutama, Southern region of Amazonas state, Brazil*

Four areas with different traditional use systems were selected, in order to evaluate possible soil erosion impacts, through areas that underwent a forest underwent a forest (*Fig. 2A*) conversion process in areas cultivated with guarana (*Fig. 2B*), annatto (*Fig. 2C*) and cupuacu (*Fig. 2D*) conversion process in areas cultivated with guarana, annatto and cupuacu. The areas were under tropical forest, and in the process of conversion to agricultural areas, the felling and burning of the forest was carried out to establish agroecosystems (*Table 1*).

Field methodology

Meshes were established according to the dimensions of the cultivation. In the guaraná and forest areas, 90 × 70 m meshes were established, with regular spacing between the sample points of 10 × 10 m, in the annatto area the meshes were of 90 × 56 m with spacing between sample points of 10 × 8 m, and in the cupuaçu area, the mesh had a 54 × 42 dimension, with regular spacing between the sample points of 6 × 6 m. The samples were collected in the intersection points of the meshes, at the 0.00-0.20 m depth point, with 80 sample points in each area, samples were collected between October and December of the 2017. The points were geo-referenced with Garmin GPS equipment, model Etrex (*Datum South American´*69).

In each sample point, it was collected samples with structures preserved in the shape of clod at the evaluated depth for the determination of the soil texture and organic carbon. The samples were dried in shade and slightly buffered, manually, sifted in 4.76 mm diameter mesh sieves, separating the retained material in the 2.00 mm sieve for the soil texture and organic carbon analyses.

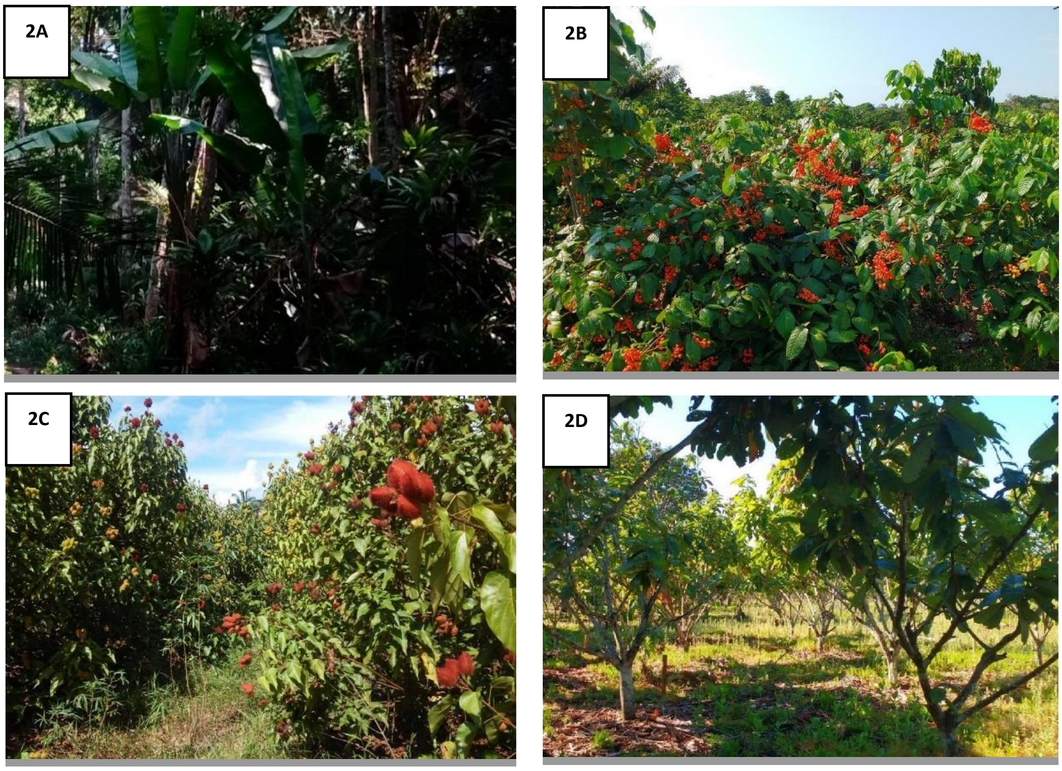

Figure 2. *Photographs of land use systems under forest, (A) conversion process in areas cultivated with guarana (B), annatto (C) and cupuacu (D), in the municipality of Canutama, Southern region of Amazonas state, Brazil*

Table 1. *Description of use and history of the areas with guarana, cupuaçu, annatto and forest, in the municipality of Canutama, Southern region of Amazonas state, Brazil*

Land use	**Use history**	**Slope (%)**	**Geographic coordinate**
Guaraná (*Paullinia cupana*)	Area resulting from felling and burning of the forest, with manual stump cleaning to clean the area in the first year of cultivation. There has never been any fertilization or liming in the cultivated areas, regular spacing of 5.0 × 5.0 m is used, with pruning and periodic cleaning to control pests, and it has been in effective cultivation for 7 years	4.0	8°13’25.7”S and 64°00’68”W
Cupuaçu (*Theobroma grandiflorum*)	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 or liming in the cultivated areas, regular spacing of 7.0 × 7.0 m is used, with pruning and periodic cleaning to control pests. It has been in effective cultivation for 7 years	0.5	8°12’53.4”S and 64°00’49.2”W
Annatto (*Bixa orellana)*	Area resulting from felling and burning of the forest, with manual stump cleaning to clean the area in the first year of cultivation. There has never been any fertilization or liming in the cultivated areas, regular spacing of 4.0 × 4.0 m is used, with pruning and periodic cleaning to control pests. It has been in effective cultivation for 3 years	2.9	8°13’20.8”S and 64°00’52.0”W
Forest	Characterized as a dense tropical rainforest, whose vegetation is evergreen, consisting of dense and multistratified trees between 20 and 50 meters in height	1.0	8°13’23.9”S and 64°00’52.4’W

Laboratory analyses

The textural analysis was made through the pipette method, using a NaOH 0.1 N solution as chemical dispersant and mechanical shaker in a high-rotation apparatus for 15 min, following the methodology suggested by Teixeira et al. (2017). The clay fraction was separated by sedimentation, the sand by screening and the silt was calculated by the difference. For the purposed of sand fractioning, common sieves with 2 mm, 1 mm, 0.5 mm, 0.250 mm, 0.125 mm and 0.053 mm meshes were used, which were shaken for 3 min using a Sieve Shaker, SOLOTEST model with digital rheostat that could read time and frequency stamps.

The organic carbon (CO) was determined by the Walkley-Black method, modified by Yeomans and Bremner (1988). The organic matter, on the other hand, was determined by the product of the CO divided by the 1.724 factor.

Determination of the erosion factors (K, K_i, K_r) and shear strength (T_c)

For the erosion estimation, indirect prediction models were used, where they estimate the erosion factors through equations that used the lab-analyzed soil attribute values. Thus, in the current papers, were used the USLE (Universal Soil Loss Equation) and WEPP (Water Erosion Prediction Project) models for the determination of the conditioning erosion factors in the studied areas.

For the USLE global soil erosion calculations (K factor_1, t ha^{-1} MJ^{-1} mm^{-1} ha h) the proposed equation was used Denardin (1990) (*Eq. 1*):

$$K = 7.48 \times 10^{-6} M + 4.48059 \times 10^{-3} p - 6.31175 \times 10^{-2} X27 + 1.039567 \times 10^{-2} X32 \quad \text{(Eq.1)}$$

in which:
M = new silt × (new silt + new sand);
p = permeability, according to Wischmeier et al. (1971) (*Table 2*);
X27 = [(0.002 × clay, %) + (0.026 × silt, %) + (0.075 × very thin sand, %) + (0.175 thin sand, %) + (0.375 medium sand, %) + (0.75 thick sand, %) + (1.5 very thick sand, %)] / (clay, % + silt, % + sand, %);
X32 = new sand × (Organic Matter, %/100).

Table 2. *Soil textural classes and permeability classes*

Textural class	Permeability class	Permeability
Very clayey, Clayey and Clay-silty	6	Very slow
Frank-clay-silty and Clay-sandy	5	Slow
Frank-clay-sandy and Frank-clayey	4	Slow and moderate
Frank, Frank-silty and Silty	3	Moderate
Sand-frank and Frank-sandy	2	Moderate and Fast
Sandy	1	Fast

For the calculation of interrill erosion of the Wepp model (Ki, kg s m^{-4}) the equations proposed by Flanagan and Livingston (1995) were used (*Eqs. 2* and *3*):

$$\text{Ki WEPP} = 2728000 + 192100\ \text{AMF, Sand} \geq 30\% \quad \text{(Eq.2)}$$

$$\text{Ki WEPP} = 6054000 - 55130\ \text{ARG, Sand} < 30\% \qquad \text{(Eq.3)}$$

in which:
AMF = very thin sand percentage, (%);
ARG = clay percentage, (%).

To calculate the rill erosion (Kr, s m^{-1}) and the shear strength (Tc, N m^{-2}) of the Wepp model, the equations proposed by Flanagan and Livingston (1995) were used (*Eqs. 4, 5, 6* and *7*):

$$\text{Kr WEPP} = 0.00197 + 0.00030\ \text{AMF} + 0.03863\ e^{(-1.84\ \text{MO})}\ \text{Sand} \geq 30\% \qquad \text{(Eq.4)}$$

$$\text{Tc WEPP} = 2.67 + 0.065\ \text{ARG} - 0.058\ \text{AMF Sand} \geq 30\% \qquad \text{(Eq.5)}$$

$$\text{Kr WEPP} = 0.0069 + 0.134\ e^{(-0.20*\text{ARG})}\ \text{Sand} < 30\% \qquad \text{(Eq.6)}$$

$$\text{Tc WEPP} = 3.5\ \text{Sand} < 30\% \qquad \text{(Eq.7)}$$

in which:
AMF = very thin sand percentage, %;
e = neperian logarithm base;
MO = soil organic matter percentage, %;
ARG = clay percentage, %.

Statistical analyses

After the determination of the erosion, texture and soil organic matter attributes, the descriptive statistic was made, as well as the univariate and multivariate statistical analyses. In the descriptive statistic, the average, median, standard deviation, variation, variation coefficient, asymmetry coefficient and kurtosis, maximum and minimum of the variables were calculated. The hypothesis of abnormality of the data was put to test with the Kolmogorov-Smirnov test, in the statistics software Statistica 7.0 (Statsoft, 2004).

The univariate analysis of variance (ANOVA) was used to compare individually averages of the attributes via Tukey test ($p < 0.05$), using the software SPSS 21 (Spss Inc., 2001). Then, multivariate analysis of variance (MANOVA) was used, through factorial analysis, in order to find statistical significance of the evaluated attribute sets that discriminate the environments the most, having as reference the area under forest, aiming to have as an answer the attributes that suffer the most influence in the respective studied areas.

The adequacy of the factorial analysis was made by the Kaiser-Meyer-Olkin (KMO) measure, which evaluates the simple and partial correlations of the variables, and by the sphericity Barlett test, to which we intend to reject the equality between the correlation axis with the identity. The factors extraction was made by the principal components analysis (ACP), incorporating the variable which displayed communalities equal or superior to five (5.0). The choosing of the number of factors to be used was made by the Kaiser criteria (factors that display auto values above 1). In order to simplify the factorial analysis, an orthogonal rotation (*Varimax*) of the factors was made and represented in a factorial plane of the two components.

The geostatistics analysis was made based on the experimental semivariogram, estimated by the equation:

$$\hat{y}(\mathrm{h}) = \frac{1}{2\eta(h)} \sum_{\mathrm{i}=1}^{\eta(h)} [\mathrm{Z}(x_{\mathrm{i}}) - \mathrm{Z}(x_{\mathrm{i}} + h)]^2 \qquad \text{(Eq.8)}$$

in which:
ŷ(h) the semivariance value for a *h* distance;
n(h) the number of pairs involved in the semivariance calculation;
Z(xi) the value of the attribute *Z* at the *xi* position;
Z(xi + h) the value of the attribute *Z* separated by a distance *h* of the *xi* position.

For the spatial dependency degree analysis (GDE) of the studied attributes, it was used the Cambardella et al. (1994) classification, in which the soil proprieties are considered to be with strong spatial dependency if the ratio of the nugget effect (C0) in relation to the threshold (C0 + C1) is less than 25%. If the ratio is between 26 and 75%, the spatial dependence is considered moderate, while if the soil propriety is bigger than 75% to approximately 95%, it is classified as a weak spatial dependence.

The semivariogram models for the studied attributes were estimated by the Software GS + 7.0 (Robertson, 2008). The semivariograms' adjustment were made based on the better determination coefficient (R^2) and maximum correlation coefficient (*r*) of the cross validation. In the variables spatial distribution map elaboration, the program Surfer 13 was used. The Pearson correlation was used to evaluate the force and direction of the distribution pattern correlation of those variables.

Results and discussion

The descriptive statistic, much like the variance analysis for the evaluated erosion attributes in areas cultivated with guarana, annatto and cupuaçu, in comparison with the forest area are presented in *Table 3*, for the depth 0.00-0.20 m. Through the results, we observe that all the evaluated attributes displayed very close average and median values, indicating that they possess normal distribution, as well as symmetrical distribution with the values of the attributes close to zero. As for the kurtosis coefficient, several of the attributes displayed negative values, thus making evident a platykurtic distribution, that is, distribution of more flattened peaks than the normal distribution (Lima et al., 2022). The respective results found were similar to the ones found by Brito et al. (2022).

As for the results referring to the Kolmogorov-Smirnov test, they indicated normality for all the erosion attributes analyzed at the depth from 0.00-0.20 m. In relation to extreme values (maximum and minimum), neighboring values for the studied variables were observed.

Adopting the variation coefficient (CV%) limits proposed by Warrick and Nielsen (1980), that consider the coefficient values below 12% as low variability, between 12% and 60% as medium variability and values above 60% as high variability. It was possible to affirm based on the (CV%) values found, that the erosion attributes displayed low variability for most of the studied attributes, with the exception of the MO in guarana, cupuaçu and forest areas, attribute clay in the guarana and annatto areas, as well as the $\mathrm{Kr}_{\mathrm{wepp}}$ factor in the annatto area, which displayed medium variability according to the established limits.

Taking into consideration that the (CV%) indicates the variability of the data in relation to the average, and that the less it is, the more homogeneous is the data set, it is possible to assess homogeneous condition for the results found in the present study. According to Frozzi et al. (2020), elevated CV values can be considered as the first indicators of the existence of heterogeneity in the data.

When the results of the variance analysis (*Table 3*) were examined by the Tukey test ($p < 0.05$), it was possible to observe that the biggest MO values followed the sequence cupuaçu > forest > annatto > guarana, in a way that the respective areas displayed significant differences. The high MO value found in the cupuaçu area is possibly associated to the vegetal coverage provided by the intake of residues from the culture from 7 years of cultivation, associated with few intensive soil practices. The current results are similar to the ones found by Jordão et al. (2021), which higher OM levels were found in areas under agroforestry systems, this result is due to the accumulation of plant material in the soil and its slow decomposition.

When the textures fractions results were analyzed, it was noted that for the sand attribute, the guarana and annatto areas did not display a significant difference between them according to the Tukey test (*Table 3*). Probably, the high sand values found in the guarana and annatto areas might be related to the topography of the respective areas, a fact that possibly favored the carrying via flood of smaller particles of the mineral fraction (clay) and organic matter, which are preferably transported by superficial runoff. In this sense, studies highlight that the terrain's topography has an accentuated influence in losses by erosion, especially due to the degree of slope and length of the slope (Campos et al., 2008).

More recently, Cerdà et al. (2017) recommended the application of straw coverage as an efficient soil handling technique, in cultivable lands with accentuated slope, aiming the reduction of the superficial draining and soil loss. A study by Souza et al. (2019 stated that the vegetal coverage produced by the plants acts in order to reduce the deleterious effects of erosion, minimizing the nutrient losses and organic carbon, in area over elevated slope.

Table 3. *Test of average and descriptive statistic of the attributes of the erosion of the soil at the depth of 0.00-0.20 m for the areas with guarana, cupuaçu, annatto and forest, in the municipality of Canutama, Southern region of Amazonas state, Brazil*

Descriptive statistic	**OM**	**Sand**	**Silt**	**Clay**	**K factor**	**Ki_{wepp}**	**Kr_{wepp}**	**Tc_{wepp}**
	$g\ kg^{-1}$	**$t\ ha^{-1}$**			**$t\ ha^{-1}\ MJ^{-1}\ mm^{-1}\ ha\ h$**	**$kg\ s\ m^{-4}$**	**$s\ m^{-1}$**	**$N\ m^{-2}$**
				Guarana				
Maximum	29.10	462.93	467.20	282.67	5.29×10^{-2}	7.10×10^{7}	1.03×10^{-2}	3.67
Minimum	12.77	307.53	378.60	120.00	4.30×10^{-2}	5.52×10^{7}	6.98×10^{-3}	2.36
Average	21.05 **d**	372.03 **a**	413.06 **c**	214.91 **c**	4.70×10^{-2} **b**	6.18×10^{7} **a**	8.31×10^{-3} **a**	3.03 **b**
Median	21.03	370.07	411.50	215.99	4.69×10^{-2}	6.15×10^{7}	8.28×10^{-3}	3.05
SD	3.18	37.86	20.75	33.63	2.12×10^{-3}	2.96×10^{6}	6.78×10^{-4}	0.25
Variance	10.14	1433.60	430.73	1131.19	1.00×10^{-5}	8.78×10^{11}	0.00	0.06
CV (%)	15.13	10.17	5.02	15.65	4.51	4.79	8.16	8.15
Asymmetry	-0.12	0.36	0.53	-0.49	0.48	0.56	0.68	-0.42
Kurtosis	0.00	-0.47	-0.36	-0.02	0.08	0.46	0.67	0.44
K-S	0.06*	0.06*	0.10*	0.09*	0.07*	0.07*	0.10*	0.09*

Annatto								
Maximum	29.34	303.13	302.93	158.67	4.15×10^{-2}	4.27×10^{7}	4.65×10^{-3}	2.35
Minimum	17.73	481.80	457.67	305.33	5.56×10^{-2}	7.40×10^{7}	1.00×10^{-2}	3.87
Average	23.79 **c**	381.62 **a**	387.54 **d**	230.84 **b**	4.70×10^{-2} **b**	6.31×10^{7} **a**	8.16×10^{-3} **a**	3.08 **b**
Median	23.93	372.03	390.30	233.33	4.70×10^{-2}	6.68×10^{7}	8.60×10^{-3}	3.11
SD	2.62	44.94	34.40	35.86	2.93×10^{-3}	8.06×10^{6}	1.31×10^{-3}	0.34
Variance	6.87	2020.05	1183.16	1285.82	9.00×10^{-6}	6.50×10^{11}	2.00×10^{-6}	0.12
CV (%)	11.01	11.78	8.81	15.53	6.23	12.77	16.11	11.09
Asymmetry	-0.19	0.41	-0.19	-0.09	0.51	-0.56	-0.60	-0.15
Kurtosis	-0.61	-0.74	-0.49	-0.94	0.77	-0.99	-0.70	-0.55
K-S	0.07*	0.10*	0.05*	0.08*	0.10*	0.19*	0.15*	0.06*
Cupuaçu								
Maximum	45.45	230.53	373.40	217.20	4.39×10^{-2}	4.22×10^{7}	7.07×10^{-3}	-
Minimum	20.87	318.87	537.07	333.20	5.78×10^{-2}	4.86×10^{7}	8.64×10^{-3}	-
Average	31.42 **a**	275.51 **b**	452.85 **b**	271.64 **a**	4.98×10^{-2} **a**	4.59×10^{7} **b**	7.63×10^{-3} **b**	3.5 **a**
Median	31.54	277.50	452.63	274.53	4.97×10^{-2}	4.59×10^{7}	7.54×10^{-3}	-
SD	5.04	20.54	34.25	25.33	2.91×10^{-3}	1.49×10^{6}	3.70×10^{-4}	-
Variance	25.42	421.84	1173.28	641.49	8.00×10^{-6}	2.21×10^{11}	0.00	-
CV (%)	16.05	7.45	7.58	9.32	5.84	3.24	4.85	-
Asymmetry	0.26	-0.17	0.27	0.13	0.40	-0.35	0.89	-
Kurtosis	0.36	-0.55	-0.20	-0.04	0.26	-0.37	0.30	-
K-S	0.07*	0.06*	0.08*	0.07*	0.07*	0.08*	0.13*	-
Forest								
Maximum	35.55	196.87	434.35	212.00	4.38×10^{-2}	4.31×10^{7}	7.14×10^{-3}	-
Minimum	18.55	284.27	558.07	316.00	5.73×10^{-2}	4.89×10^{7}	7.97×10^{-3}	-
Average	26.67 **b**	242.99 **c**	492.17 **a**	260.84 **a**	4.90×10^{-2} **a**	4.61×10^{7} **b**	7.58×10^{-3} **b**	3.5 **a**
Median	26.67	243.33	490.43	260.00	4.90×10^{-2}	4.62×10^{7}	7.63×10^{-3}	-
SD	3.40	19.98	26.33	23.04	2.64×10^{-3}	1.27×10^{6}	1.99×10^{-4}	-
Variance	11.58	399.09	693.30	530.79	7.00×10^{-6}	1.61×10^{11}	0.00	-
CV (%)	12.76	8.22	5.35	8.83	5.39	2.75	2.63	-
Asymmetry	0.38	-0.22	0.10	-0.14	0.40	0.14	-0.07	-
Kurtosis	0.35	-0.51	-0.41	-0.35	0.96	-0.35	-0.57	-
K-S	0.07*	0.06*	0.05*	0.06*	0.09*	0.06*	0.10*	-

SD: standard deviation; CV: coefficient of variation (%); K-S: Kolmogorov-Smirnov normality test. *Significant at 5% probability; OM: Organic Matter; K Factor: global soil erosion; Ki_{wepp}: interrill erosion; Kr_{wepp}: rill erosion; Tc_{wepp}: shear strength; (wepp: water erosion prediction project); Averages followed by the same lowercase letter in the column do not differ from each other by Tukey’s test ($p < 0.05$)

When analyzing the silt values, it was possible to observe bigger values in the forest areas with values around 492.17 g kg^{-1}, also displaying significant difference when compared to the guarana, annatto and cupuaçu areas. When the clay values were evaluated, it was noted that the cupuaçu and forest areas did not display significant difference among them by the Tukey test at a 0.05 probability rate. Such results just prove that the respective areas displayed differentiated and inverted behavior in relation to the guarana and annatto areas, in such a way that while the cupuaçu and forest areas displayed bigger clay values, the ucurum areas displayed bigger sand values.

Possibly in virtue of the cupuaçu and forest areas being localized in areas that are considered to be more plain, this may have enabled lesser conditions of loss of sediments provided by the hydric erosion, as it is the main form of Brazilian soil degradation, stemming from the joint action of rain drops and flood that, besides suspended soil particles, transports nutrients, organic matter and chemical substances, causing serious problems to the agricultural activities (Silva et al., 2021). Overall, it was possible to assess based on the results that the sand, silt and clay levels are characterized as medium texture in all the studied areas.

When analyzing the results of global erosion, it was noted that the studied areas displayed very close K values, ranging from 4.70×10^{-2} to 4.98×10^{-2} t ha^{-1} MJ^{-1} mm^{-1} ha, showing bigger values in the cupuaçu and forest areas (*Table 3*). To justify such results, we have to first understand that the determination of the erosion propriety (K factor) is complex due to the many variables involved, factor that has sparked the curiosity in erosion research, as it is ruled by the soil's intrinsic attributes, which can vary from soil to soil according to texture and type of management (Panagos et al., 2015).

In face of such clarification, it is possible to assess that probably the type of soil and the high silt values found in the forest and cupuaçu areas provided bigger susceptibility of the areas to erosion. In this sense, such results may be considered, as the K factor just displays the predisposition of the areas to erosion. The found results may be proved by other studies, where they also observe higher erosion indexes in soils with high silt and sand levels (Taleshian Jeloudar et al., 2018). The respective attributes lack adhesion proprieties and, if hydrated, they become easily broken and transported, having a bigger effect on the soil erosion (Huang et al., 2022). Overall, when assessing the found (K factor) results, we observe that they were inferior to 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 soil loss equation in Argissolos (Chromic Abruptic Acrisol) in the Southern region of Amazonas.

According to Castro et al. (2011), the soil erosion might be classified in classes according to its potential, in a way that the respective authors use the following classifications: $K < 9.00 \times 10^{-3}$ (very low); $9.00 \times 10^{-3} < K \leq 1.50 \times 10^{-2}$ (low); $1.50 \times 10^{-2} < K \leq 3.00 \times 10^{-2}$ (average); $3.00 \times 10^{-2} < K \leq 4.50 \times 10^{-2}$ (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 consideration that the values found in the studied areas had a variation from 4.70×10^{-2} to 4.98×10^{-2} t ha^{-1} MJ^{-1} mm^{-1} ha, it was possible to identify the found values in the class (very high), a fact that already raises concerns in regards to the adoption of erosion mitigating and conservationist agricultural production support practices.

Upon analyzing the results obtained from Ki_{wepp} and Kr_{wepp} factors in all the studied areas, it was possible to observe that the guarana and ucurum areas did not display significant differences among them. Based on the found results, it is possible to assess that the guarana and annatto areas displayed bigger predisposition to suffer interrill erosion (Ki_{wepp}) and rill (Kr_{wepp}). The average values of the erosion factors of the soil (Ki_{wepp} and Kr_{wepp}) were bigger than the ones obtained by Franco et al. (2012) who studied the soil erosion interrill in Argissolo Vermelho, obtaining an average value of 1.82×10^6 kg s m^{-4}.

When analyzing the found critical shear strength results, it was possible to observe a possible direct relation with the erosion values (K factor), as they followed the same tendency of the K factor results found, observing bigger values in the cupuaçu and forest areas, in a way that both did not display significant differences among them with the Tukey test at a 0.05 probability rate. In the respective areas the erosion coefficients were bigger, an indication that they were very susceptible to erosion, but, with critical shear strength values also high, a fact that indicates resistance to the early parts of the erosive process. A similar diagnostic was found by Silva et al. (2021). On the other hand we can assess that if the present areas begin to have a bigger effectiveness of the anthropic area, without the adoption of efficient criteria and handling practices, they have a big change of evolving the erosion risks, leading to losses that could be avoided. Studies highlight that the parameter determination of critical shear strength and erosion make it possible to evaluate the soil's resistance, and they are viable alternatives to be adopted in the planning of the hydric control planning (Madenoglu et al., 2020).

In *Table 4*, there are the values of the Pearson correlation at the 0.01 significance level, for the erosion attributes of all the studied areas. It was possible to observe that the attribute MO displayed positive correlation with silt (r = 0.39), clay (r = 0.46), K factor (r = 0.45) and Tc_{weep} (r = 0.48). Those findings do not corroborate with the ones found by Ostovari et al. (2016) where they observed negative correlation between MO and K factor.

Table 4. *Pearson Correlation of the erosion attributes in areas with guarana, cupuaçu, annatto and forest, in the municipality of Canutama, Southern region of Amazonas state, Brazil*

Attributes	**MO**	**Sand**	**Silt**	**Clay**	**K factor**	**Ki_{wepp}**	**Kr_{wepp}**	**Tc_{wepp}**
MO	1.00	-0.55^{**}	0.39^{**}	0.46^{**}	0.45^{**}	-0.47^{**}	-0.33^{**}	0.48^{**}
Sand		1.00	-0.82^{**}	-0.69^{**}	-0.29^{**}	0.79^{**}	0.41^{**}	-0.84^{**}
Silt			1.00	0.22^{**}	0.52^{**}	-0.70^{**}	-0.27^{**}	0.58^{**}
Clay				1.00	-0.05^{ns}	-0.47^{**}	-0.37^{**}	0.76^{**}
K Factor					1.00	-0.18^{**}	0.15^{**}	0.04^{ns}
Ki Wepp						1.00	0.69^{**}	-0.81^{**}
Kr Wepp							1.00	-0.64^{**}
Tc Wepp								1.00

** = significant to the level of 1% probability; ns = not significant. K factor: global soil erosion; Ki_{wepp}: interrill erosion; Kr_{wepp}: rill erosion; Tc_{wepp}: shear strength; (wepp: Hydric erosion prediction project)

On the other hand the studies indicated that the MO is affected by the attributes sand (r = -0.55), Ki_{weep} (r = -0.47) and Kr_{weep} (r = -0.33), both displaying negative correlation. When analyzing the Pearson correlation for the attribute sand, it was noted that the present attribute displayed positive correlation with Ki_{weep} and Kr_{weep}, but it had negative correlation with the attributes silt, clay, K factor and Tc_{weep}. The work developed by Taleshian Jeloudar et al. (2018) also found a negative correlation of sand with the silt and K factor attributes. For the attribute silt, it was identified a positive correlation with the attributes clay, K factor and Tc_{weep}, and the negative correlation was observed with the attributes Ki_{weep} e Kr_{weep}.

When analyzed the Pearson correlation of the clay attribute, it was possible to identify that the respective attribute displayed positive correlation with Tc_{weep}, and the negative correlation followed the same tendency of the silt attribute, which also displayed correlation with the attributes Ki_{weep} and Kr_{weep}. A noteworthy fact was the observation of non-significant correlation of the attribute clay with K factor. When analyzing the K factor, there was a positive correlation with the Kr_{weep} attribute, a negative correlation with Ki_{weep}, as well as a non-significant correlation with the Tc_{weep} attribute. In regards to the attribute Ki_{weep}, it was observed that it displayed positive correlation with the attribute Kr_{weep} and negative with $Tc_{weep.}$ The attribute Kr_{weep} displayed negative correlation with the attribute Tc_{weep} (*Table 4*).

It is important to highlight that the positive correlation causes a direct effect, that is, as there is an increase of the analyzed attribute, there will be an increase of the positively correlated attribute. The negative correlation indicates an antagonistic effect of other analyzed attributes, in a way that the increasing of those will provide for a decrease in the attributes that had negative correlation.

The adjustments of the experimental semivariograms, kriging maps and spatial dependency analyses are presented in *Figures 3* and *4*. It was possible to observe through the results that the attributes displayed spatial dependency, adjusting predominantly to the exponential and spherical models, with R^2 and CV values above 0.76 and 0.78, respectively.

Upon analyzing the results of the spatial dependency degree (SDD), expressed by the ratio between the nugget effect and the level, the Cambardella et al. classification (1994), it was noted that the attributes were displayed at the limits of the spatial dependency degree, ranging between moderate to strong dependency. Such results corroborate with the ones found by Miqueloni e Bueno (2011), also doing multivariate analysis and spatial variability at the estimate of the erosion of an Argissolo Vermelho-Amarelo.

Through the results, it was possible to observe bigger SDD values for the attribute Kr_{wepp} in the annatto area and MO in the forest area, both presenting a value around 50%, making evident the moderate spatial dependency degree (*Fig. 3*).

The smallest SDD values were attributed for the attribute clay in the annatto area and MO in the cupuaçu area, both displaying the 0.05% value, making evident a strong degree of spatial dependency (*Fig. 3*). The smaller this relation $[C_0/(C_0 + C)]x100$, the smaller is the relative value of the nugget effect, and, consequently, better spatially set is the studied attribute (Souza et al., 2020). The areas that displayed bigger attribute concentrations with strong spatial dependency were the guarana, annatto and cupuaçu areas.

The reach (a) is a geostatistics parameter that indicates the limit between points correlated between them. Currently it has served as a subside in sample planning, as the reach values imply, in general terms, in bigger or smaller sample density (Soares et al., 2018). Based on the found results, it was noted that the studied variables displayed different reach values, in a way that the smaller values were observed in the cupuaçu area, for the MO attribute in the order of 12.1 m. As for the reach values for the other attributes, taking in consideration all the studied areas, they were around 20.7 to 89.9 m, that means that all the neighbors inside this range can be used in the value estimation in nearby spacing. Such results also showed that the sample mesh could get the spatial variability of the attributes and that the value estimations made by kriging generated trustworthy values (*Fig. 4*).

The kriging maps make it able to incur, also, that the erosion attributes displayed a quite homogenous spatial distribution. In this sense, it is worth highlighting that the use of variability maps allows us to geographically localize the problematic areas, with the possibility of localized intervention in the zones that display levels or values of said non-desirable (Soares et al., 2021). Based on such clarification, it was possible to observe through the kriging maps, the regions that displayed bigger concentrations of sand, silt, clay and organic matter, much like the regions that displayed bigger predisposition to suffer soil erosion, such fact ends up being an important prevention parameter of soil usage and handling.

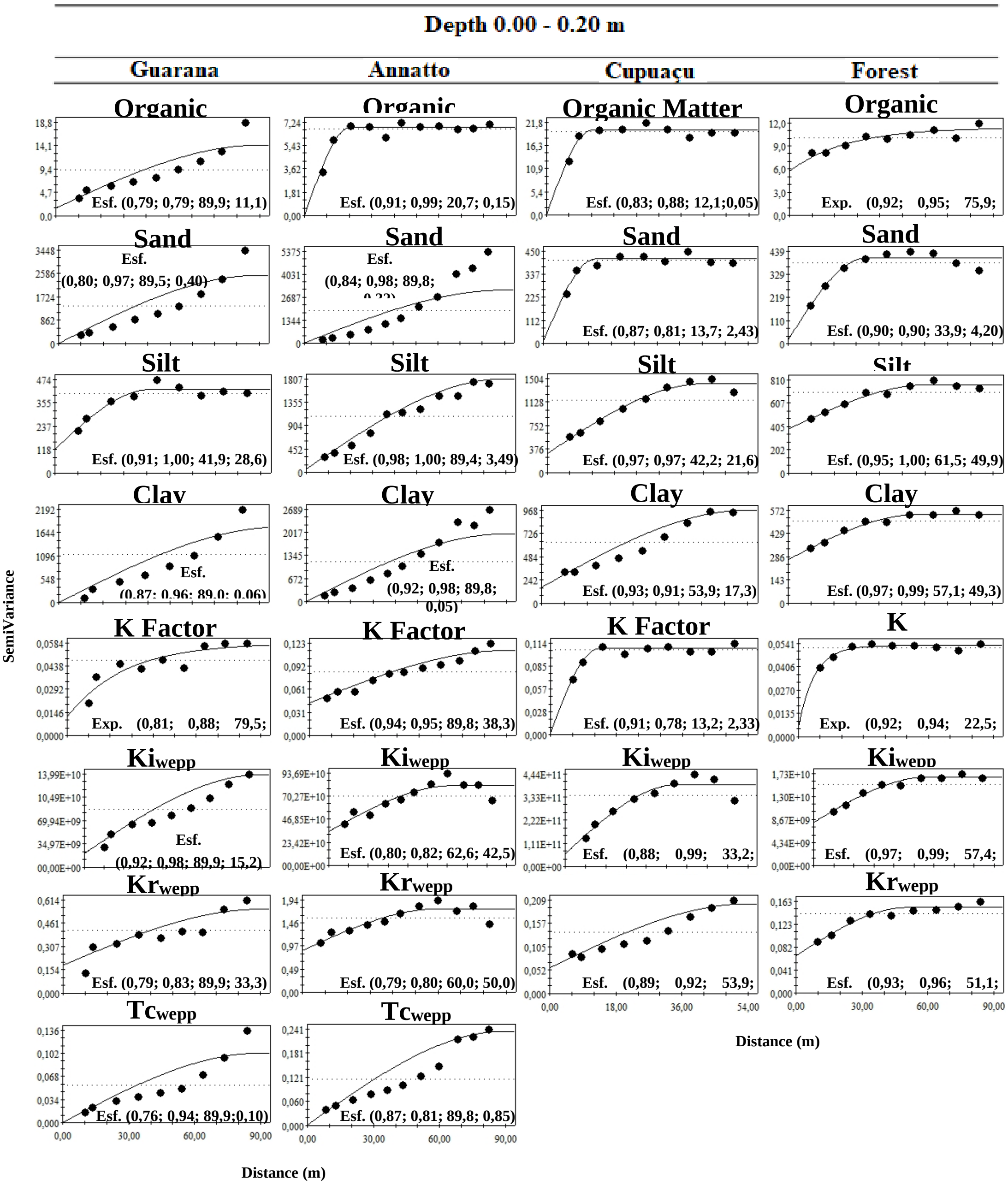

__Figure 3.__ Adjusted experimental semivariograms of the erosion attributes at the depth of 0.00 to 0.20 m in areas with guarana, cupuaçu, annatto and forest, in the municipality of Canutama, Southern region of Amazonas state, Brazil. K factor: global soil erosion; Kiwepp: interrill erosion; Krwepp: rill erosion; Tcwepp: shear strength; (Wepp: Hydric erosion prediction project). Model (R2, CV, reach and e SDD)

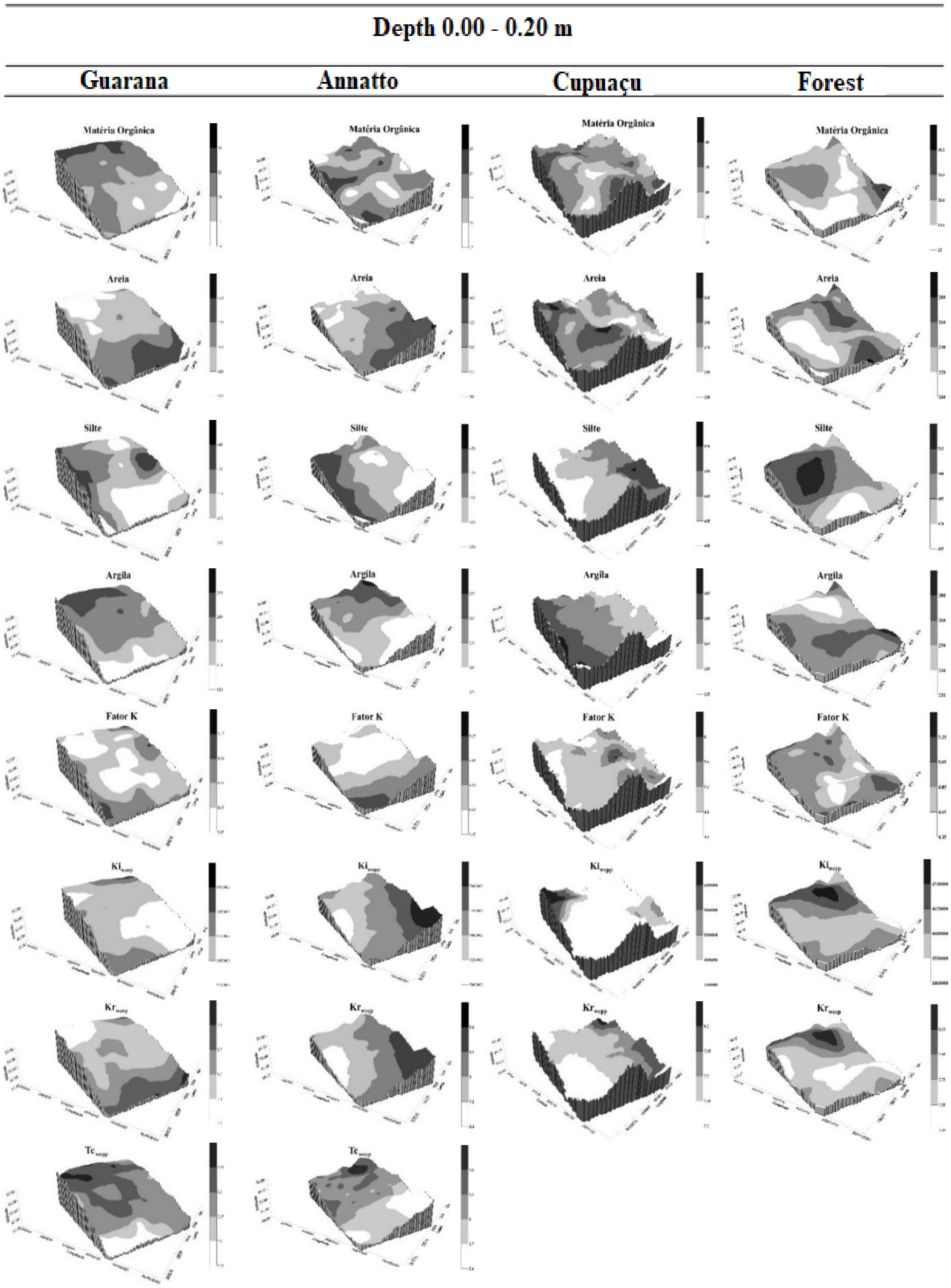

Figure 4. *Kriging map of the attributes organic matter, sand, silt, clay, K factor, Ki*$_{wepp}$*, Kr*$_{wepp}$*, Tc*$_{wepp}$ *in areas with guarana, cupuaçu, annatto and forest, in the municipality of Canutama, Southern region of Amazonas state, Brazil. K factor: global soil erosion; Ki*$_{wepp}$*: interrill erosion; Kr*$_{wepp}$*: rill erosion; Tc*$_{wepp}$*: shear strength; (wepp: hydric erosion prediction project)*

Despite the occurrence of spatial distribution for all the analyzed erosion factors, it is important to highlight direct influence of the terrain in the guarana and annatto areas, as such fact may indicate the occurrence of sludge loading, due to the superficial draining of the higher parts to the lower parts of the areas.

In the multivariate analysis, it was observed that the soil erosion attributes that suffered the biggest alteration after the conversion process of forest to areas cultivated with Amazon species. The adequacy of the factorial analysis was shown to be significant with (KMO equal to 0.70 and $p < 0.05$ for Bartlett's sphericity test), the current paper suggests that the data of the evaluated attributes are adequate to the factorial analysis. In the Principal Components Analysis (PCA), the number of factors to be extracted was established in order to explain over 70% of the total variance of the data (*Table 5; Fig. 5*), which displayed autovalues of the matrix of covariance superior to one (1) (Frozzi et al., 2020), with 3.59 at principal components (CP1) and 1.99 at principal components (CP2).

Table 5. *Correlation between each principal components and analyzed variables and factorial analysis of the soil attributes with the rotated factors (Varimax) (Factor 1 and 2) corresponding to the areas with guarana, cupuaçu, annatto and forest, in the municipality of Canutama, Southern region of Amazonas state, Brazil*

Attributes	**Common Variance**	**Factors**	
		PC1	**PC2**
Sand	0.96	-0.77*	-0.56
Silt	0.93	0.45	0.82*
Clay	0.89	0.78*	-0.01
K Factor	0.43	-0.17	0.89*
Ki_{wepp}	0.82	-0.82*	-0.40
Kr_{wepp}	0.63	-0.78*	0.11
Tc_{wepp}	0.88	0.93*	0.22
	Explained Variance (%)	59.17	20.65

K factor: global soil erosion; Ki_{wepp}: interrill erosion; Kr_{wepp}: rill erosion; Tc_{wepp}: shear strength; (wepp: hydric erosion prediction project)

The two principal components retain 79.82% of the percentage of the explained variance, with the first (CP1) having 59.17% of the total variance, and the second (CP2), represented a value around 20.65%. Both the first and the second factor (*Table 5*) displayed explanation percentage for the attributes of soil erosion and texture. As such, CP1 discriminated better the attributes (sand, clay, Ki_{wepp}, Kr_{wepp} e Tc_{wepp}), while CP2 discriminated the attributes (silt and K factor). In the first situation, for the attributes that better discriminated the CP1, it can be inferred that the higher the clay and Tc_{wepp} values, the lower will be the soil predisposition to erosion in rill (Kr_{wepp}) and interrill (Ki_{wepp}), besides lower sand levels.

The present inverse correlation of the clay displaying negative correlation with the sand can be explained by the particular condition of each attribute in the soil (*Table 5*). Despite sandy soils retaining more water due to their bigger pores, they allow for the non-occurrence of draining, having in mind the low proportion of clay, being easily carried even by low-intensity rains. In contrast, a clayey soil, with smaller pores and reduced infiltration, will be more resistant to draining, given the cohesion of its particles (Jiang et al., 2020).

When the second component CP2 is analyzed, it is noted that it displays a direct correlation of the K factor with the silt, showing that the bigger the quantity of this fraction, the bigger the erosion and effectiveness of the erosive process (Miqueloni and Bueno, 2011).

In *Figure 5*, the analysis of principal components, through the score distribution of the different studied areas and the disposition of the factorial charges of the soil attributes formed by PC1 and PC2 is represented. Based on the results, it was possible to observe a bigger densification of the forest and cupuaçu areas scores in the first quadrant, which reveals that both obtained values from the silt, clay K factor and Tc_{wepp} attributes, above average. On the other hand, the areas cultivated with guarana and annatto were more thickened in the third quadrant, with attributes turned to characteristics that indicate the soil predisposition to rill erosion and interrill, in such a way that the sand and Ki_{wepp} attributes displayed below average values and the Kr_{wepp} attribute above average value, such susceptibility condition might be related to the terrain's topography, as the respective areas are being cultivated in a local that displays 3% declivity, fact that ends up favoring the carrying via flood of the soil particles.

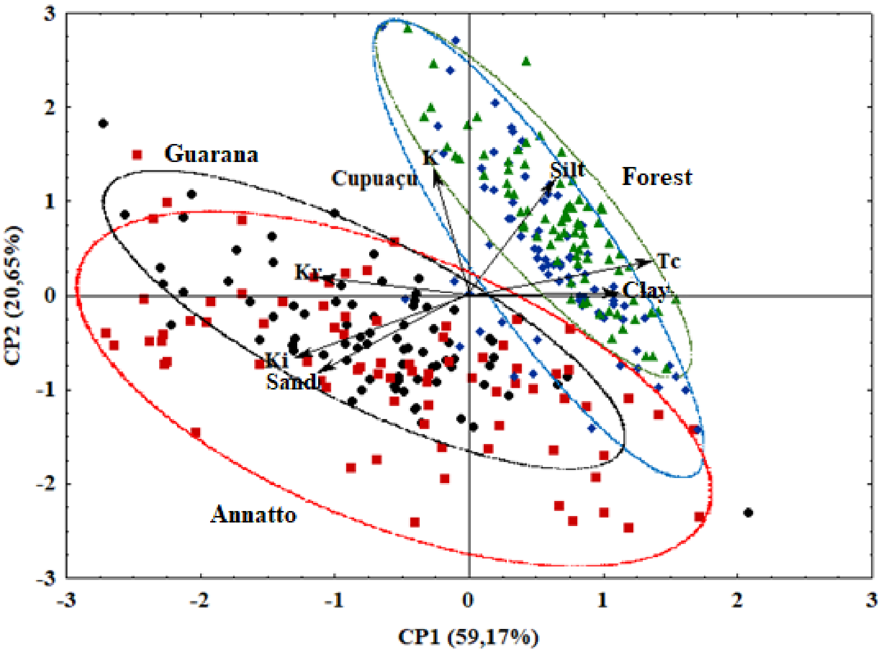

Figure 5. *Principal Components Analysis of the studied soil attributes at the depth of 0.00 to 0.20 m, in areas with guarana, cupuaçu, annatto and forest, in the municipality of Canutama, Southern region of Amazonas state, Brazil*

Conclusions

The cultivated areas with guarana and annatto displayed bigger soil predisposition to rill erosion (Kr_{wepp}) and interrill (Ki_{wepp}).

The cupuaçu and forest areas displayed elevated silt values, favoring erosion conditions (K factor), in contrast they also displayed elevated shear critical tension values, a fact that indicates resistance to the beginning of the erosive process.

The integrated form geostatistic with the multivariate analysis helped in the understanding of the behavior of erosion factors, after the process of native forest/cultivated areas conversion.

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