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Article

Estimating soil erodibility in areas under natural and anthropped environments in the southern region of Amazonas State

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ABSTRACT: Amazonian soils have been suffering severe changes resulting from human activities in the region, causing significant changes in soil attributes that can contribute to greater susceptibility to erosion processes. Therefore, the present work aimed to estimate the erodibility in natural and anthropic environments in the southern region of the Amazon. Eight areas in the region were selected, including areas of native forest, savannah, cerradão, pasture and reforestation, delimiting 32 sampling points per area, with collections at a depth of 0.00-0.20 m, totaling 256 samples. Next, texture analysis and quantification of soil organic carbon were performed, and then erodibility was estimated by indirect prediction methods, Tukey's test, Pearson's correlation and factorial analysis of principal components. According to the results obtained, it was observed that the evaluated areas of native forest 1 and 2, cerradão and pasture present high susceptibility to erosion in relation to the cerrado, reforestation with genipap, teak and mixed areas. Therefore, it was noted that the high level of erodibility is associated with a greater predominance of sand fraction, K factor, Ki Kr and low clay content, as well as with the management employed in the areas.

Key words: soil attributes, erosive process, soil management, amazonian soils.

INTRODUCTION

The intensive use of natural resources, the lack of planning in the use and in the occupation of the land, associated with the lack of public policies for the preservation of the environment have caused changes in the attributes of soils, resulting in serious damage and environmental impacts on the environment. The process of occupation of the Legal Amazon was characterized by the incorrect use of natural resources, mainly the soil (Nascimento and Fernandes 2017). As a result of the destruction of vegetation, represented by different biomes, in which it was fragmented, these spaces were converted to agricultural and pasture activities (Souza et al. 2018). On the other hand, the soil is one of the essential natural resources in the planning of human activities, in which it presents vital functions and services in the ecosystem, which include climate change mitigation and food security (Schaefer et al. 2017).

Nonetheless, the soils in the southern region of Amazonas state have been undergoing changes due to the replacement of forest areas by the most diverse systems of uses, without proper knowledge and compliance with technical criteria, and this has been one of the main problems in the region (Frozzi et al. 2020), which has led to the acceleration of erosive processes, causing damage to the ecosystem. According to Duarte et al. (2020), this fact can result in the loss of soil nutrients, increase in production costs and decline in crop yields. Therefore, a study aimed at evaluating the susceptibility associated with soil losses in environments undergoing forest conversion for agricultural uses in the Amazon region is necessary (Lima et al. 2020), as the diagnosis and monitoring of the natural erosion potential and the risks of degradation, contribute to the planning of land use and occupation (Nunes et al. 2017).

In this context, in order to estimate the erodibility, some studies used indirect methods, because, among other characteristics, it has a low cost and provides important information for diagnosing the use and management activities. It can be highlighted a study carried out by Brito et al. (2020), who studied the estimation of erodibility in areas of Terras Preta de Índio under the use of cocoa, pasture and coffee in the region of Apuí, Amazonas state; Lourenço et al. (2020), who studied the estimation of erodibility in areas of Terras Preta de Índio, under forest and pasture use in the region of Novo Aripuanã, Amazonas state; and Lima et al. (2020), who studied the estimation of erodibility in forest conversion areas in areas of cultivation with cocoa, cupuaçu and guaraná in the region of Canutama, Amazonas state, all indicating that the change in land cover brings an increase in susceptibility and, consequently, the loss of soils.

Knowledge of changes in soil attributes caused by various anthropogenic uses provides assistance for the adoption of management practices that allow increasing the yield of the production process with the conservation of environments (Souza et al. 2020). For Oliveira et al. (2020), although several scientific works and the efforts of a large number of researchers have contributed to the advancement of knowledge of soils in the southern region of Amazonas state, there is a need to expand this knowledge for a better compression of Amazonian ecosystems. Given the above, the objective of this work was to estimate the erodibility in natural and anthropogenic environments in the southern region of Amazonas state.

METHODS

Location and characterization of the study areas

The study was carried out between January and March 2020 in areas of the municipality of Humaitá, southern Amazonas state (Brazil). The native forest areas 1 (FN1) (07°34’27”S and 63°06’53”W); cerrado (7º34’27.37” S and 63º7’57.28”W); cerradão (7º34’19.70” S and 63º7’49.66” W) are located at km 20, on the BR-319, towards Humaitá – Manaus, in an area belonging to the 54th Infantry Battalion of the Brazilian Army. Pasture areas (7°23’59”S and 63°12’97”W) and native forest 2 (FN2) (7°24’12”S and 63°12’58W) are located on a private property in the km 45 of the BR-319 towards Manaus reforestation areas with teak (07°34’33”S and 63°06’51”W); genipap reforestation (07°34’41”S and 63 °06’49”W); mixed reforestation (teak, genipap, andiroba, kapok and mahogany) (07°34’54”S and 63°06’55”W) is located on a private property located in km 18 of BR-319 towards Manaus, AM state (Fig. 1).

With regard to geology, the study area is formed by sedimentary materials formed by claystones and siltstones from the Solimões Formation, from the Middle Pliocene - Upper Pleistocene, originating from depositions of continental, fluvial and lake environments (Brasil 1978). In these environments, there are Haplic Cambisols (Inceptisols), Haplic Gleissolos (Alfisols) and Red Ultisols (Ultisols), all characterized by low natural fertility and located in areas of flat to smooth undulating relief (Fonseca et al. 2021).

Regarding the climatic characterization, the climate of the region, according to Köppen’s classification, belongs to group A (Tropical Rainy Weather) and climatic type Am (monsoon rain), with annual precipitation ranging from 2,250 to 2,750 mm, average temperature annual ranging between 24 and 26 ºC and relative humidity ranging between 85 and 90% (Brasil 1978). According to the National Institute of Meteorology (INMET), the rainy period in the region occurs between October and March and the dry period occurs between June and August, considering the other months as a transition period, with an average precipitation of around 2,220 mm in 2020.

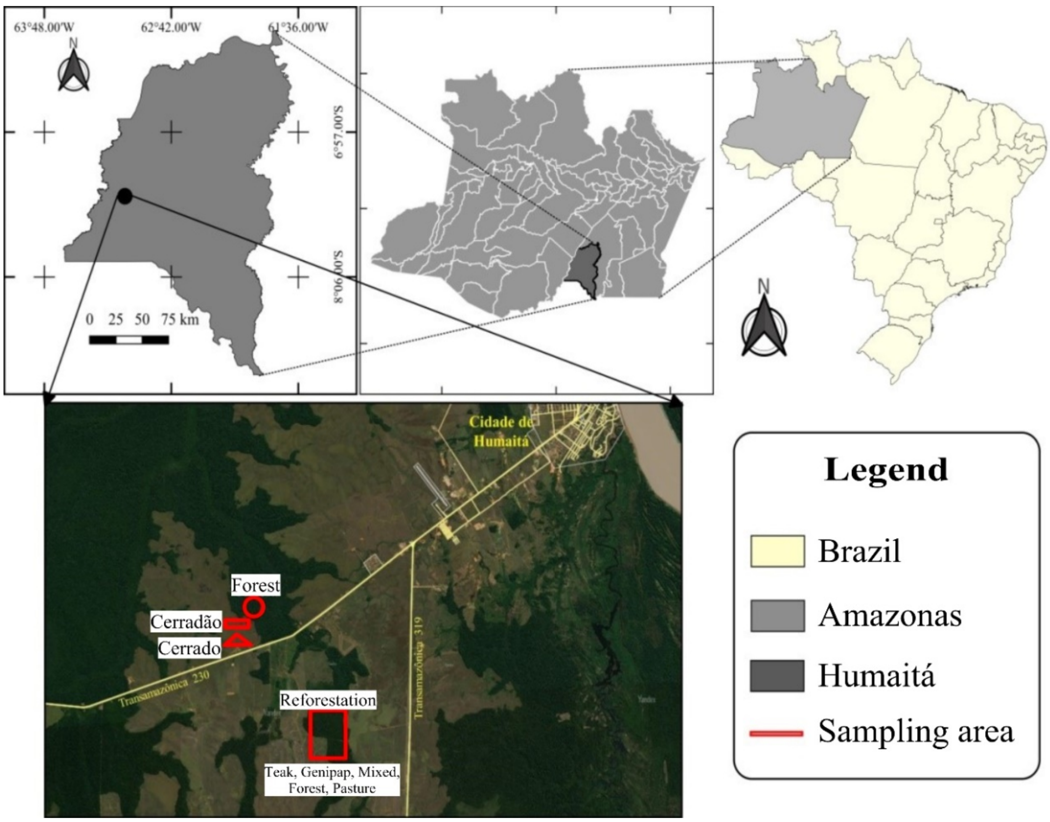

Figure 1. Location of Study Areas. Map of the state of Amazonas, highlighting the eight study areas in the municipality of Humaitá-AM state. The areas studied had the following characteristics, according to Table 1.

Source: Elaborated by the authors.

Table 1. History of use and management of the areas selected for the study.

Use	Handling
Native Forest 1	Higher and better draining area of the landscape, with an open ombrophilous forest phytophysiognomy, with palms and other trees between 20 and 50 m in height, with the presence of Euterpe precatoria, Vismia guianensis, Orbignya speciosa, Oenocarpus bacaba, Attalea speciosa and Mabea subsessilis (Campos et al., 2012).
Native Forest 2	Area with dense forest, with evergreen vegetation, with the presence of phanerophytes, consisting of dense and multi-layered trees between 20 and 50 meters in height.
Cerrado	Composed of shrubby vegetation (Campos et al., 2010) and occurrence of species of the genera Andropogon and Paspalum, twisted and spaced trees, such as Curatella americana L. and Eupatorium sp. (Campos et al., 2012), which are subject to fire, acting as a disruptive element of the system.
Cerradão	Composed of shrubs and a thin scrub vegetation ("capoeira") (Santos et al., 2012), having among its most important species, Sclerolobium paniculatum, Himatanthus sucuuba and Mabea caudata (Campos et al., 2012).
Pasture	Area with pasture (Brachiaria decumens) for ten years, resulting from felling and burning of the forest, with manual destocking to clear the area in the first year of cultivation, without fertilization and liming, only weed control using a motorized cutter and spraying with glyphosate herbicide to control thatch (Imperata brasiliensis).
Teak reforestation (*Tectona grandis* L.):	Implemented over 10 years ago, from the replacement of pasture, incorporating 1.5 tons of limestone per hectare, before planting forest species, with teak (Tectona grandis L.) being planted with a spacing of 3x3 m.
Genipap reforestation (*Genipa americana* L.):	Implemented over 10 years ago, arising from the replacement of pasture, with incorporation of 1.5 tons of limestone per hectare, before planting forest species, being planted jenipapo (Genipa americana L.) with a spacing of 3x3 m.
Mixed Reforestation	Implemented over 10 years ago, arising from the replacement of pasture, incorporating 1.5 tons of limestone per hectare, before planting forest species, planting mahogany (Swietenia macrophylla King.), andiroba (Carapa guianensis Aubl.) species.), jenipapo (Genipa americana L.), teak (Tectona grandis L.) and sumauma (Ceiba pentandra) with 4x3 m spacing.

Source: Elaborated by the authors.

Field Methodology

In each studied area (native forest 1 and 2, cerrado, cerradão, pasture, teak, genipap and mixed reforestation area), 32 collection points were selected in the central part of an area equivalent to one hectare and then samples were collected of soil randomly using a Dutch auger at a depth of 0.00-0.20 m, making a total of 256 samples in the studied areas.

Laboratory analysis

The collected soil samples were dried in the shade and then manually broken down, passing them through a 2.00 mm diameter sieve. Then, the total organic carbon content (TOC) was determined by the Walkley-Black method (1934), modified by Yeomans and Bremner (1988) and the soil organic matter was estimated.

The particle size analysis was performed using the pipette method, with a 1 $mol \cdot L^{-1}$ NaOH solution as chemical dispersant and mechanical agitation in a high speed stirrer for 15 minutes. The sand was separated by sieving and clay and silt were separated by sedimentation (Teixeira et al. 2017).

Then, the sand fractions were sieved to determine the dimensions of the analyzed solid particles, aiming to estimate the erodibility factors. For the analysis, a sieves shaker, model SOLOTEST with digital rheostat, time and frequency marker, was used to fractionate the particles through vibrations that accelerate the sieving. Each sample was shaken for 3 minutes using common sieves with 2 mm mesh; 1 mm; 0.5 mm; 0.250 mm; 0.125 mm and 0.053 mm.

To estimate the erodibility, indirect prediction models were used, where they estimate the values of the erodibility factor through equations that involve information on the soil attributes analyzed in the laboratory. In the present work, the erodibility factor of the USLE model (Universal Soil Loss Equation) was estimated using equations, using the method for soils in Brazil (Silva et al. 2021) and the USA and equations of the WEPP model (Water Erosion Prediction Project) (Flanagan and Livingston 1995) to determine the conditioning factors of erosion in the areas under study.

To calculate the erodibility (K factor, $t \cdot ha^{-1}\ MJ^{-1}\ mm^{-1}\ ha^{-1}\ h$), the aforementioned factor of the USLE modified by Lima et al. (2021) was used to evaluate K in Brazilian soils, according to Eq. 1:

$$K = 7.48 \times 10^{-6}\ m + 4.48059 \times 10^{-3}\ p - 6.31175 \times 10^{-2}\ X27 + 1.039567 \times 10^{-2}\ X32 \tag{1}$$

where New silt = silt + very fine sand, %; New sand = very coarse sand + coarse sand + medium sand + fine sand, %; M = new silt x (new silt + new sand); X27 = [(0.002 x clay, %) + (0.026 x silt, %) + (0.075 x very fine sand, %) + (0.175 fine sand, %) + (0.375 medium sand, %) + (0.75 sand coarse, %) + (1.5 very coarse sand, %)] / (clay, % + silt, % + sand, %); X32 = new sand x (Organic Matter, %/100).

To estimate the values of water permeability (p) in the soil (Table 2), the classification by Wischmeier et al. (1971) built together with the Department of Agriculture's National Soils Handbook No. 430 (USDA 1983).

Table 2. Soil texture and permeability class.

Texture class[1]	Permeability[2]	
	Class	Classification
Very clayey, clayey and silty clay	6	too slow
Silt-clay loam and sandy-clay loam	5	Slow
Sandy clay loam and clay loam	4	slow and moderate
Franca, Franco-siltosa and Siltosa	3	Moderate
Loose sand and sandy loam	2	moderate and fast
sandy	1	Fast

Source: United States Department of Agriculture (1983); Wischmeier et al. (1971).

The equations proposed by Flanagan and Livingston (1995) (Eq. 2 and 3) were used to calculate the erodibility in the Wepp model (Ki, $kg \cdot s \cdot m^{-4}$):

$$sand \geq 30\%\ Ki\ Wepp = 2728000 + 192100\ AMF \quad (2)$$

$$sand < 30\%\ Ki\ Wepp = 6054000 - 55130\ ARG \quad (3)$$

where , the equations proposed by Flanagan & Livingston (1995) (Eq. 4, 5, 6 and 7):

$$sand \geq 30\%\ Kr\ Wepp = 0{,}00197 + 0{,}00030\ AMF + 0{,}03863\ e^{(-1{,}84\ MO)} \quad (4)$$

$$sand < 30\%\ Kr\ Wepp = 0{,}0069 + 0{,}134\ e^{(-0{,}20*ARG)} \quad (5)$$

$$sand \geq 30\%\ TC\ Wepp = 2{,}67 + 0{,}065\ ARG - 0{,}058\ AMF \quad (6)$$

$$sand < 30\%\ TC\ Wepp = 3{,}5 \quad (7)$$

Statistical analysis

After the obtention of the datas soils attributes, was realized the descriptive analyses where was it obtained the mean and the variation coefficient, next in the mean was realized the tukey test, that objective is liken the differences that exist in between environmentals, is positive, whats the significance, is being harmful of the environmental, this all using the Completely Randomized Design (DIC) of form that the differents invironmentals was the trataments, that is, only liken be between the environmentals.

After obtaining the erodibility data, descriptive statistical analyzes were performed, in which the mean and coefficient of variation were calculated. Then, the analysis of variance was performed comparing the areas studied by Tukey's test at 5% probability.

Subsequently, the Pearson correlation analyzes were performed at 5% probability and the correlation matrix was assembled for the combinations, two by two, between the attributes using the SPSS 21 software (IBM Corp. 2021). In addition, the regression analysis was performed between global erodibility and variables that were corrected.

For the multivariate analyses, the factor analysis of the principal components (PCA) was performed in order to find the statistical significance of the sets of soil attributes that most discriminate the environments, in relation to the different areas under study, obtaining the answer which they are the environments whose attributes are most influenced by anthropic action.

The suitability of the factor analysis was performed by the Kaiser-Meyer-Olkin (KMO) measure, which assesses the simple and partial correlations of the variables, and by the Bartlett sphericity test, which is intended to reject the equality between the correlation matrix with the identity. The extraction of factors will be performed by principal component analysis, incorporating variables that have commonalities equal to or greater than five (5.0). The choice of the number of factors to be used was made using the Kaiser criterion (factors with eigenvalues greater than 1.0). In order to simplify the factor analysis, the orthogonal rotation (varimax) was performed and represented in a factorial plane of the variables and scores for the main components.

In PCA scatter plots after varimax rotation, scores were constructed with standardized values, such that the mean is zero and the distance between scores is measured in terms of standard deviation. Thus, the variables in the same quadrant (1st, 2nd, 3rd and 4th) and closer together in the PCA scatter plot are better correlated. Likewise, scores assigned to samples that are close together and in the same quadrant are related to the variables in that quadrant (Lima et al. 2022).

RESULTS AND DISCUSSION

In Table 3, descriptive statistics data and the mean test of erodibility attributes in the 0.00-0.20 m layer in natural and anthropogenic environments are present.

Table 3. Descriptive statistics and mean test of soil attributes and erodibility factors in the 0.00 – 0.20 m layer in natural environment areas and anthropogenic environments in the southern region of Amazonas state.

Variable	Mean (N=32)	Median	Standard deviation	[1]CV%	Skewness	Kurtosis	[2]K-S
Native Forest 1							
Sand ($g \cdot kg^{-1}$)	152.4d	158.00	60.60	39.75	-0.18	-0.83	0.09
Silt ($g \cdot kg^{-1}$)	335.8ab	309.60	149.30	44.46	0.62	-0.28	0.14
Clay ($g \cdot kg^{-1}$)	511.7abc	514.40	124.50	24.34	-0.27	-0.65	0.11
[3]SOM ($g \cdot kg^{-1}$)	91.7b	91.78	13.28	14.47	-0.55	0.59	0.08
[4]K	0.517ab	0.05	0.01	15.55	0.16	-1.25	0.13
[5]Kiwepp	$3.23E^{+06}$b	3.22^{+06}	6.87^{+05}	21.24	0.27	-0.65	0.11
[6]Krwepp	0.07ab	0.01	0.00	2.27	3.91	16.54	0.36
[7]τc wepp	3.50c	3.50	0.00	0.00	*	*	*
Native Forest 2							
Sand ($g \cdot kg^{-1}$)	189.3de	186.50	51.09	26.98	-0.31	-0.40	0.11
Silt ($g \cdot kg^{-1}$)	273.9bc	270.40	103.30	37.71	2.71	11.74	0.20
Clay ($g \cdot kg^{-1}$)	536.7a	527.10	100.70	18.75	-0.78	3.38	0.18
[3]SOM ($g \cdot kg^{-1}$)	102.5a	102.11	7.10	6.92	0.24	0.00	0.16
[4]K	0.597a	0.06	0.02	40.22	4.63	23.96	0.30
[5]Kiwepp	$3.10E^{+06}$d	$3.15E^{+06}$	$5.66E^{+05}$	18.26	0.68	2.87	0.17
[6]Krwepp	0.069ab	0.01	0.00	6.57	2.72	17.32	0.45
[7]τc wepp	3.50c	3.50	0.00	0.00	*	*	*
Cerrado							
Sand ($g \cdot kg^{-1}$)	220.1cd	221.00	43.80	19.90	-0.18	-0.69	0.09
Silt ($g \cdot kg^{-1}$)	266.6bc	257.20	63.10	23.65	0.36	-1.07	0.17
Clay ($g \cdot kg^{-1}$)	513.2abc	487.10	66.90	13.03	0.38	-0.54	0.19
[3]SOM ($g \cdot kg^{-1}$)	59.5c	57.77	8.01	13.45	0.70	-0.50	0.15
[4]K	0.463bc	0.05	0.00	10.03	-0.21	-0.32	0.08
[5]Kiwepp	$3.22E^{+06}$d	$3.37E^{+06}$	$3.69E^{+05}$	11.43	-0.38	-0.54	0.19
[6]Krwepp	0.070 ab	0.01	0.00	4.10	5.47	29.91	0.50
[7]τc wepp	3.50c	3.50	0.00	0.00	*	*	*
Cerradão							
Sand ($g \cdot kg^{-1}$)	371.4a	399.50	97.20	26.18	-2.61	6.62	0.28
Silt ($g \cdot kg^{-1}$)	141.4d	143.90	62.50	44.17	1.97	7.39	0.19
Clay ($g \cdot kg^{-1}$)	480.2abc	487.10	97.20	20.23	1.22	3.65	0.21
[3]SOM ($g \cdot kg^{-1}$)	64.3c	64.49	7.29	11.33	-0.52	0.56	0.13
[4]K	0.534ab	0.05	0.01	16.54	-0.31	1.25	0.11
[5]Kiwepp	$4.85E^{+06}$a	$5.12E^{+06}$	$9.27E^{+05}$	19.10	-2.69	6.58	0.39
[6]Krwepp	0. 059b	0.01	0.00	7.87	1.08	0.56	0.15
[7]τc wepp	4.75a	4.83	0.59	12.49	-1.02	0.52	0.21
Pasture							
Sand ($g \cdot kg^{-1}$)	294.8b	288.70	75.50	25.62	-0.61	0.29	0.10
Silt ($g \cdot kg^{-1}$)	243.8c	231.70	85.80	35.19	1.21	1.73	0.15
Clay ($g \cdot kg^{-1}$)	461.3bcd	467.10	87.90	19.06	-0.58	1.47	0.19
[3]SOM ($g \cdot kg^{-1}$)	47.0d	45.28	29.30	62.25	0.15	-0.72	0.10
[4]K	0. 455bc	0.05	0.01	28.79	0.20	-0.86	0.13
[5]Kiwepp	$4.17E^{+06}$b	$4.67E^{+06}$	$9.32E^{+05}$	22.37	-0.21	-1.51	0.22
[6]Krwepp	0. 074a	0.01	0.01	71.10	5.29	28.63	0.44
[7]τc wepp	4.14b	3.50	0.85	20.49	1.16	1.00	0.32

Continue...

Table 3. Continuation...

Variable	Mean (N=32)	Median	Standard deviation	1CV%	Skewness	Kurtosis	²K-S
			Reforestation with Genipap				
Sand ($g \cdot kg^{-1}$)	256.8bc	251.30	56.00	21.81	0.00	2.68	0.15
Silt ($g \cdot kg^{-1}$)	208.8cd	198.70	95.30	45.60	2.25	9.32	0.18
Clay ($g \cdot kg^{-1}$)	534.2ab	534.50	78.50	14.69	-0.32	2.00	0.12
³SOM ($g \cdot kg^{-1}$)	85.5b	85.09	7.31	8.54	0.68	0.80	0.09
⁴K	0. 447bc	0.04	0.01	11.51	0.57	0.81	0.18
⁵Kiwepp	$3.22E^{+06}$d	$3.11E^{+06}$	$6.85E^{+05}$	21.26	1.65	3.33	0.25
⁶Krwepp	0. 068ab	0.01	0.00	4.78	-3.42	10.94	0.52
⁷τc wepp	3.58c	3.50	0.32	8.89	3.86	13.95	0.54
			Reforestation with Teak				
Sand ($g \cdot kg^{-1}$)	231.6cd	242.50	40.90	17.66	-0.26	-0.61	0.12
Silt ($g \cdot kg^{-1}$)	382.4a	360.50	81.90	21.41	1.23	0.72	0.25
Clay ($g \cdot kg^{-1}$)	401.6d	394.80	66.30	16.52	-0.62	0.99	0.08
³SOM ($g \cdot kg^{-1}$)	33.0e	33.97	3.37	10.20	-0.23	-0.97	0.17
⁴K	0.391c	0.04	0.01	18.07	1.35	2.36	0.18
⁵Kiwepp	$3.99E^{+06}$bc	$3.88E^{+06}$	$4.73E^{+05}$	11.88	0.94	-0.26	0.19
⁶Krwepp	0.069ab	0.01	0.00	9.96	0.24	4.23	0.39
⁷τc wepp	3.57c	3.50	0.25	6.96	2.95	7.21	0.53
			Mixed Reforestation				
Sand ($g \cdot kg^{-1}$)	188.7de	189.00	41.56	22.02	-0.36	0.11	0.11
Silt ($g \cdot kg^{-1}$)	355. 6a	366.50	64.90	18.26	-0.40	-0.53	0.13
Clay ($g \cdot kg^{-1}$)	455.6cd	426.40	78.20	17.17	0.98	0.25	0.19
³SOM ($g \cdot kg^{-1}$)	33.5e	33.90	4.44	13.24	0.57	0.53	0.09
⁴K	0.443bc	0.05	0.01	11.50	-0.34	-0.77	0.14
⁵Kiwepp	$3.54E^{+06}$cd	$3.70E^{+06}$	$4.31E^{+05}$	12.17	-0.98	0.25	0.19
⁶Krwepp	0.069 ab	0.01	0.00	0.45	1.54	2.30	0.18
⁷τc wepp	3.50c	3.50	0.00	0.00	*	*	*

[1]CV%: coefficient of variation, %; [2]K-S: normality test (Kolmogorov-Smirnov significant at 5%); [3]SOM: organic matter; K: soil erodibility, $t \cdot ha^{-1}.MJ^{-1} \cdot mm^{-1} \cdot ha \cdot h$; Ki wepp: erodibility in ridges, $kg \cdot s \cdot m^{-4}$; Kr wepp: furrow erodibility, $kg \cdot N^{-1} \cdot s^{-1}$; τc wepp: shear stress, $N \cdot m^{-2}$. Means followed by different letters in the same column are significantly different at the level of <5% by Tukey's test. Source: Elaborated by the authors.

In the sand fraction mean test, it was observed that the values ranged from 371.4 to 152.4, $g \cdot kg^{-1}$ in descending order had: cerradão > pasture > genipap > teak > cerrado > FN2 > mixed > FN1. Silt values ranged from 141.40 to 382.40 $g \cdot kg^{-1}$, starting in the area cerradão > genipap > pasture > cerrado > FN2 > FN1 > mixed > teak, while the clay fraction ranged from 401.70 to 536.70 $g \cdot kg^{-1}$ teak > mixed > pasture > cerradão > FN1 > cerrado > genipap > FN2.

As for the contents of soil organic matter (SOM), they presented mean values ranging from 33.07 to 102.55 $g \cdot kg^{-1}$, in the following ascending order: teak > mixed > pasture > cerrado > cerradão > genipap> FN1 > FN2, it is noteworthy that the areas in natural environment had higher content of soil organic matter when compared to areas under cultivation.

The mean K factor ranged from 0.04 to 0.06 $t \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1} \cdot ha \cdot h$, starting in the genipap > teak > mixed > FN1 > cerrado > cerradão > pasture > FN2 area. In the classification of the K factor, it was observed that the areas of genipap, teak and mixed reforestation were classified as areas of high erodibility, whereas the areas of FN1 and FN2, cerrado, cerradão and pasture presented very high erodibility.

The mean Ki wepp factor ranged from 3.10E+06 to 4.85E+06 $kg \cdot s \cdot m^{-4}$, with increasing values from the area FN2 > cerrado > genipap > FN1 > mixed > teak > pasture > cerradão. It was observed that the natural (FN1 and FN2 and cerrado) and crop areas (genipap, teak and mixed) have lower averages compared to pasture (4.17E+06 $kg \cdot s \cdot m^{-4}$) and cerradão (4.17E+06 $kg \cdot s \cdot m^{-4}$) and cerradão (4 .85E+06 $kg \cdot s \cdot m^{-4}$). The Kr wepp factor in all areas studied showed constant values

(0.01 kg·N^{-1}·s^{-1}). The factor τcwepp had an average ranging from 3.50 to 4.76 N·m^{-2}, starting in the area FN1 > FN2 > cerrado > mixed > genipap > teak > pasture > cerradão, while the values of Tc wepp were low in all areas. When the K factor was considered, the areas in general are fragile to erosion.

The adequacy of the factor analysis was significant with KMO equal to 0.56 and $p < 0.05$ for Bartett's sphericity test, which suggests that the data in Fig. 2a and b are suitable attributes for the factor analysis. In the principal component analysis (PCA), the number of extracted factors was established in order to explain that the total variance of the data Fig. 2a was above 70%, which presented high values of the covariance matrix greater than 1 (one), with 50, 41% and 22.56% in PC2 (Fig. 2b).

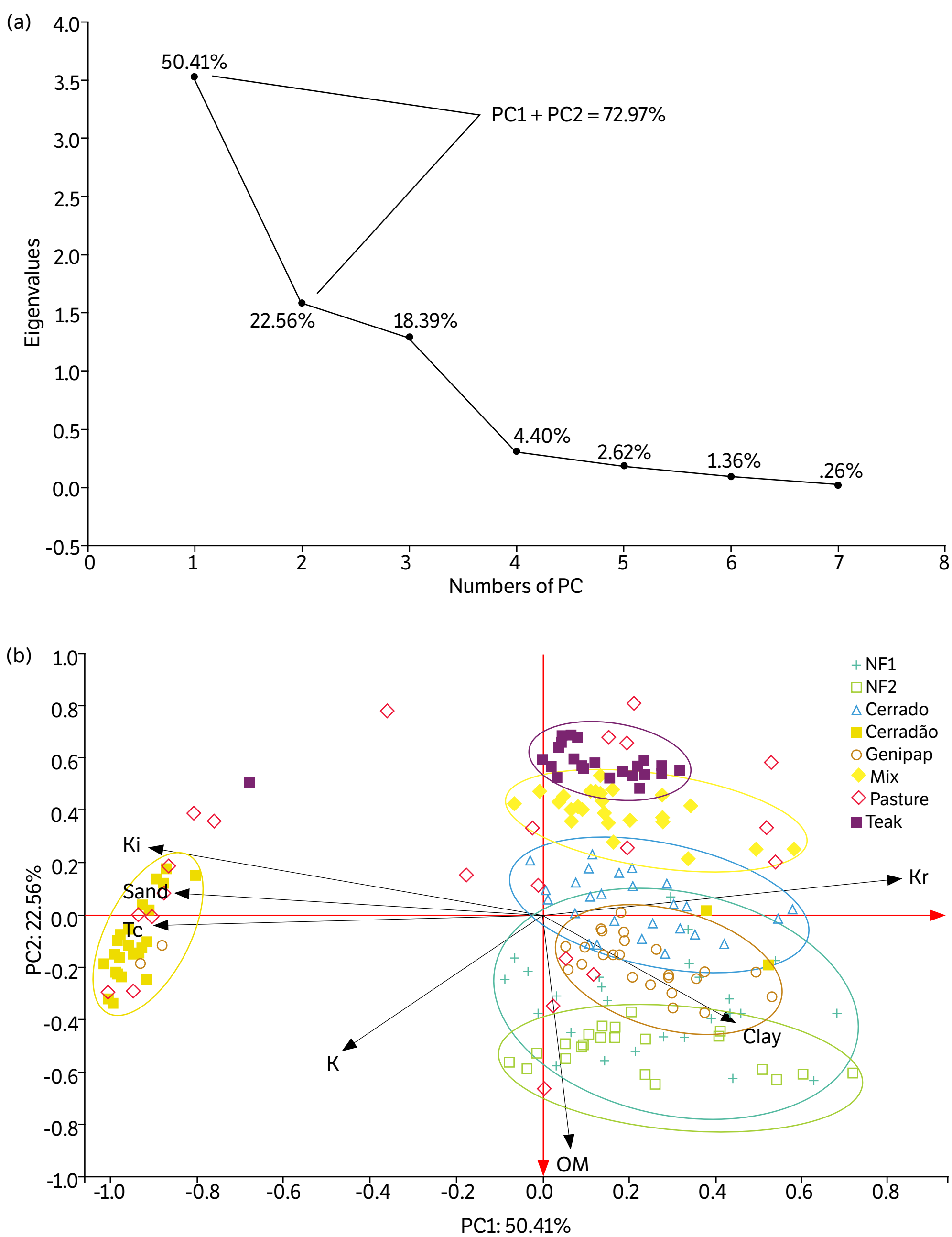

Figure 2. A) Correlation of the value between each component and analyzed variables and factors of soil attributes with the factors (eigenvalues) of the principal components (PC1 and PC2); B) Analysis of principal components of the attributes of the soils studied in the 0.00 – 0.20 m layer for the areas FN1, FN2, cerrado, cerradão, pasture, genipap, teak and mixed, in southern Amazonas - AM state.

Source: Elaborated by the authors.

The results of the principal component analysis are shown in Fig. 3, where it was possible to verify that the areas of FN1e FN2 and genipap had a high content of soil organic matter (SOM), combined with a higher clay content, thus causing low K factor values, and even with a smaller amount of vegetation cover, cerrado also showed low signs of more laminar and superficial erosion (Kr). The areas under cultivation of reforestation with teak and mixed showed opposite behavior, as they had higher values of silt, which contributes to a high rate of Kr wepp. It was also possible to verify that the cerrado area has a greater relationship with sand associated with global erodibility (K) and interrill erodibility (Ki).

The parameters involved in the data analysis showed that the attributes present normality via the KS test for soil variables (Lourenço et al. 2020), whereas the coefficient of variation varied between low and medium variability, according to the classification of Warrick and Nielsen (1980), confirmed by the values of close median means. According to Santos et al. (2018), in relation to the textural classification of soils, all areas proved to be of the clayey type, with small variations in clay content between areas.

Clay soil has a large water retention capacity, has a large volume of porosity, associated with the management adopted in the area (Lima et al. 2020). However, vegetation cover is essential to ensure the soil stability (Souza et al. 2023). Thus, anthropized soils present variation in the physical structure of the soil, associated with the management adopted (Cunha et al. 2016). Therefore, the assessment of soil texture is essential for understanding the behavior and management of the soil, and based on it, management practice decisions can be made (Centeno et al. 2017).

The high content SOM values in the natural environment are due to the management systems adopted in agricultural crops that have a great influence on the carbon stock, which may decrease, maintain or increase in relation to the area's native vegetation (Silva et al. 2021), as well as the diversity of organisms present in natural environments which, in turn, a certain percentage is lost in the conversion of environments to anthropized places, which organisms are responsible for the decomposition of organic material and the incorporation of carbon and nutrients into the soil (Gonçalves and Santana 2019).

Thus, it is worth mentioning that SOM plays a significant role in maintaining the physical, chemical and biological quality of the soil, contributing to the sustainability and productivity of agricultural systems, reducing erosion by surface runoff (Silva et al. 2014).

The high values of the K factor end up exposing weaknesses within the soil structure, predicting that there must be greater attention and care, it is noteworthy that, in both cases, a conservation management plan in these places is necessary to mitigate and to prevent evolution to higher levels of erosion (gullies and large erosion areas) (Souza et al. 2023).

These global erodibility behaviors may be directly related to soil texture and organic matter content, which influence the stability of soil aggregates. In the study carried out by Paula et al. (2023), he states that the aggregation process involves a set of elements, including organic matter, which acts as a cementing agent uniting the soil particles. In this case, the greater the stability of the aggregates by the soil organic matter, the lesser the occurrence of erosion. However, the area with a high level of erodibility becomes more susceptible to the occurrence of erosion (Lima et al. 2020).

Regarding the erosion between ridges, it is important to emphasize, first, that the Ki values corroborate the values presented by Brito et al. (2020). Evidencing that pasture and cerradão are more susceptible to erosion between furrows.

This evidence can be related to the lower ground cover provided by this type of vegetation, as there is an enormous similarity between them. According to Souza et al. (2023), the erosion between the furrows is strongly influenced by the soil surface conditions, represented by the absence or presence of vegetation cover, the roughness of the soil surface and the slope on the ground. The soil cover has an important effect to minimize inter-rill erosion. Plant residues on the soil surface intercept raindrops and dissipate their energy, preventing the breakdown of particles (Brito et al. 2020). In addition, there is a reduction in the speed of the runoff and, consequently, a reduction in its ability to disaggregate and to transport particles (Silva et al. 2021).

The behavior of the Kr factor was similar to those found by Paula et al. (2023), in which the furrow erodibility (Kr) was negatively correlated with soil attributes in natural areas and positively correlated with cultivated areas, that is, cultivated environments tend to increase erodibility in furrows, demonstrating a problem of hydraulics and runoff in these environments (Dantas et al. 2014).

When evaluating the shear stress (Tc), it is important to highlight that it is directly related to the K factor, once it is the maximum stress that can be applied to the soil without removing its particles (Lourenço et al. 2020). Thus, the smaller the value of the critical cohesion force associated with the high value of K, the greater the predictions of soil erosion (Brito et al. 2020). The relationship between cerradão and sand, K and Ki evidences the easy detachment of particles in this environment in a natural way (Corrêa et al. 2015).

The high content of organic matter in the soil influences its structure and stability (Costa et al. 2013). Thus, the importance of clay in the soil in the aggregation and stabilization of soil aggregates is justified, once it contributes to greater resistance against erosive processes (Brito et al. 2020).

CONCLUSION

Cerradão and pasture presented greater erosion risks in relation to the other areas once they have higher sand and lower clay contents, even with high values of critical shear stress.

The evaluated areas show that FN1, FN2, cerradão and pasture have a high level of erodibility in relation to cerrado, genipap, teak and mixed areas.

Thus, it is observed that the change in land use and its occupation by various anthropic activities in an unplanned way can alter and degrade the environment, impacting the agricultural productivity, degrading the soil and causing economic instability in society, which further accelerates the erosive process.

AUTHORS' CONTRIBUTION

Conceptualization: Hassane A.L., Campos M.C.C., Santos L.A.C. ,Silva D.M.P; **Methodology:** Hassane A.L., Campos M.C.C., Santos L.A.C., Silva D.M.P; **Investigation:** Hassane A.L., Campos M.C.C., Santos L.A.C., Silva D.M.P.; **Writing – Original Draft:** Santos R.B., Cunha J.M., Brito W.B.M.; **Writing – Review and Editing: L**ima A.F.L., Brito Filho E.G., Oliveira F.P.

DATA AVAILABILITY STATEMENT

No data sets were generated or analyzed during the current study.

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