Diversitas Journal
ISSN 2525-5215
Volume 8, Number 3 (Jul./Sept. 2023) p. 1390 - 1410
https://diversitasjournal.com.br/diversitas_journal

Multivariate analysis in the estimation of the erodibility of Latosols in Alagoas

Análise multivariada na estimative da erodibilidade de Latossolos de Alagoas

MARTINS, Felipe Ferreira⁽¹⁾; NASCIMENTO, Mayara Rodrgiues⁽²⁾; NASCIMENTO, Maiane Rodrigues do⁽³⁾; GOIS, Renato Luis Tertuliano de⁽⁴⁾; SANTOS, Márcio Aurélio Lins dos⁽⁵⁾; SANTOS, Cícero Gomes dos⁽⁶⁾

Authors must be identified according to the indication below, Georgia 8, the data must be complete and the Orcid valid, with the 16 digits as indicated below.

(1) 0000-0001-9016-6351; Alagoas Federal University. Arapiraca, AL, Brazil.fmartin.ufal@gmail.com.
(2) 0000-0002-4124-3282; Alagoas Federal University. Arapiraca, AL, Brazil. mayararodrigues011@gmail.com.
(3) 0000-0002-4170-5694; Alagoas Federal University. Maceió, AL, Brazil. maianerodrigues707@gmail.com.
(4) 0000-0002-0858-2880; Alagoas Federal University. Maceió, AL, Brazil. renatogois08@gmail.com.
(5) 0000-0001-5216-4443; Alagoas Federal University. Arapiraca, AL, Brazil. mal.santo@arapiraca.ufal.br.
(6) 0000-0002-2264-6772 Alagoas Federal University. Arapiraca, AL, Brazil. cgomes@arapiraca.ufal.br

ABSTRACT

Soil erodibility is one of the most important factors in understanding the erosive process. In view of the need to explore methods for determining the values of erodibility by simulated rainfall, the objective was to evaluate, through the tools of multivariate statistics, the erodibility of Latosols from Alagoas influenced by the physical, chemical and stability attributes of aggregates. The research activities were carried out at the Arapiraca *Campus*, of the Federal University of Alagoas (*Universidade Federal de Alagoas*), where Latosols were used in the suborders Red, Yellow and Red-Yellow, collected in two of the three geomorphological regions of the state of Alagoas. The prediction of correlation metrics shows that the cluster grouping indicates that the best correlations found were between the variables: clay and clay dispersed in water (r = 0.94), lime and sand (r = 90), and between the Water Erosion Prediction Project and the erodibility factor in midgrooves (r = 1.00). These strong positive correlations are proven through scatterplots, confidence regions, dendrogram, density estimation, and ellipses. The multivariate statistics allow a better understanding of the behavior of the correlations between the physical, chemical and stability attributes of aggregates with the erodibility of Latosols of Alagoas, as well as demonstrating the relationship of the variables studied with any of the three suborders of soils of Alagoas (Yellow, Red and Red-Yellow Latosol).

RESUME

A erodibilidade do solo é um dos fatores mais importantes no entendimento do processo erosivo. Tendo em vista a necessidade de se explorar métodos de determinação dos valores de erodibilidade por chuva simulada objetivou -se avaliar, por meio das ferramentas da estatística multivariada a erodibilidade de Latossolos de Alagoas influenciadas pelos atributos físicos, químicos e de estabilidade de agregados. As atividades de pesquisa foram realizadas no *Campus* Arapiraca, da Universidade Federal de Alagoas, onde, foram utilizados Latossolos nas subordens Vermelho, Amarelo e Vermelho-Amarelo, coletados em duas das três regiões geomorfológicas do estado de Alagoas. A previsão das métricas de correlação demonstram que o agrupamento de cluster indica que as melhores correlações encontradas foram entre as variáveis: argila e argila dispersa em água (r = 0,94), Lima e areia (r = 90), e entre a Water Erosion Prediction Project e o fator erodibilidade em entressulcos (r = 1,00). Essas fortes correlações positivas ficam comprovadas através dos gráficos de dispersão, as regiões de confiança, o dendrograma, a estimativa de densidade e as elipses. A estatística multivariada permite o maior entendimento do comportamento das correlações entre os atributos físicos, químicos e de estabilidade de agregados com a erodibilidade de Latossolos de Alagoas, como também demonstra a relação das variáveis estudadas com alguma das três subordens de solos de Alagoas (Latossolo Amarelo, Vermelho e Vermelho-Amarelo).

ARTICLE INFORMATION

Article process:
Submitted: 21/02/2023
Approved: 04/04/2023
Published:03/07/2023

Keywords:
Clusters, Principal components, Correlation, Soil.

Keywords:
Agrupamentos, Componentes principais, Correlação, Solo.

DOI: 10.48017/dj.v8i3.2610

Introduction

Soil is a collection of natural bodies, resulting from the interaction of geological, topographic, biological and climatic factors, considered a complex system, resulting from the interaction of geological, topographic and climatic factors, among others, that will define the characteristics of the soil (PRAGANA et al., 2012). The order of Latosols, occupy more than 50% of the Brazilian territory (OLIVEIRA, 2011), the same is verified state of Alagoas, as the occurrence of the suborders Red, Yellow and Red-Yellow (SANTOS et al., 2018). Oxisols are characterized by advanced stages of formation, with the presence of colloidal material with low cation exchange capacity (SANTOS et al., 2018). Nunes; Cassol (2008) evaluated erosive processes as very important factors with regard to damage caused to soils of agricultural systems, negatively interfering and promoting increased costs in production.

Erodibility is defined as the susceptility of a soil to water erosion (BOCUTI et al., 2019). For Thomaz; Fidalski (2020), the conditions for a soil to be susceptible to erosion is directly related to its properties. Soil erodibility values are used, among other aspects, to establish a scale of natural susceptibility of soils to water erosion (BERTOL et al., 2007).

Soil erodibility is represented by the factor K, one of the terms of the Universal Soil Loss Equation (EUPS), defined by Wischmeier and Smith (1978) while in the WEPP (Water Erosion Prediction Project) (FLANAGAN and NEARING, 1995) it represents the intergroove erosion (Ki) that expresses the amount of soil lost per unit area. The erodibility of the soil is one of the very important factors in the understanding of the erosive process, but it´s the factor of greatest cost and delay to obtain it (SILVA et al., 1999).

The erodibility factor of a soil or soil order can be obtained in three different ways. The method of natural rain, developed by Wischmeier; Smith (1978) which consists of the use of plots with totally uncovered soil, exposed to climatic conditions, this method is costly and very time-consuming, because it requires at least five years of daily observations. Trying to solve the issue of slowness and costs, the methods of determining the values of erodibility by simulated rain were developed, which can be determined in the field or under laboratory conditions (FLANAGAN; NEARINNG, 1995). The third method is indirect, which can be based on multiple regressions that contain as independent variables morphological, chemical, physical and mineralogical attributes of the soil or relations of these, correlated with the erodiability factor. In the literature, direct methods by natural or simulated rainfall are considered standard in the determination of soil erodibility values.

For Mota et al. (2014) the multivariate analysis presents a diversity of techniques that favor the evaluation of a range of data simultaneously, making it possible to observe how the variables are related to each other. Methods such as principal component analysis (PCA) and cluster analysis can be used to explain the relationships between the different variables, thus allowing to make the best decisions for agriculture-related work (SAED-MOUCHESHI et al., 2013).

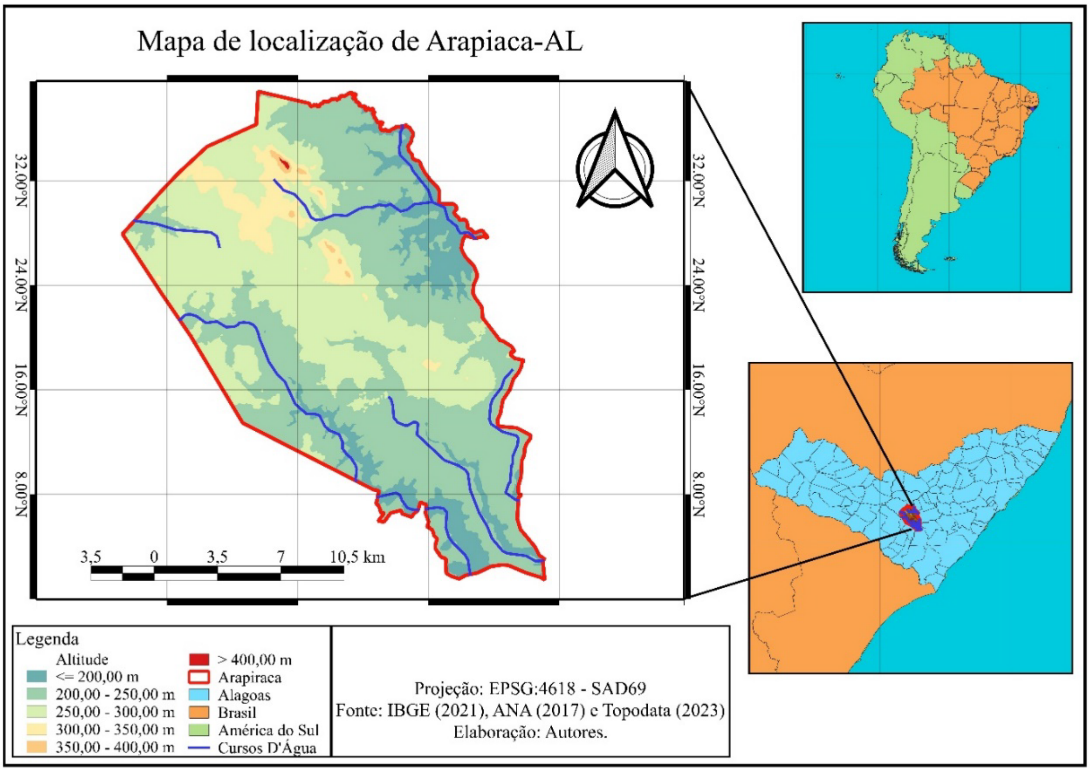
This study aimed to evaluate the soil erodibility of the Latosols of occurrence in the State of Alagoas, through the tools of multivariate statistics.

Material and Methods

The research activities for the construction of this work were carried out at the Arapiraca *Campus*, of the Federal University of Alagoas (*Universidade Federal de Alagoas*), located in the county of Arapiraca, Agreste region of the State of Alagoas, Brazil (IBGE, 2020), geodesic coordinates 9°41'56.8" of South latitude and 36°41' 12.83" of West longitude and altitude of 210.54 m (Figure 1).

Figure 1.

Federal University of Alagoas, Arapiraca campus (Universidade Federal de Alagoas, campus Arapiraca).



Source: The authors (2023).

Soils used in the research

In this research, Latosols were used, in the suborders Red, Yellow and Red-Yellow, collected in two of the three geomorphological regions of the state of Alagoas, Brazil. The samples were collected in the modal profiles of each order, in their respective suborders, with the help of the ZAAL (Agroecological Zoning of Alagoas) and the private archives of some companies in the sugar-alcohol sector of the State of Alagoas. The location of the collections and other information are shown in Table 1.

Table 1.

Locations of samples collected from the occurrence of Latosols, in the suborders Red, Yellow and Red-Yellow in the State of Alagoas.

Samples collected	Collection location	Geomorphological Region	Mesoregion
Red Latosol 1 (LV1)	Arapiraca	Pediplane of the Baixo São Francisco	Agreste alagoano
Red Latosol 2 (LV2)	Girau do Ponciano	Pediplane of the Baixo São Francisco	Agreste alagoano
Red Latosol 3 (LV3)	Limoeiro de Anadia	Tabuleiro Costeiro	Agreste alagoano
Yellow Latosol 1 (LA1)	Coruripe	Tabuleiro Costeiro	Leste alagoano
Yellow Latosol 2 (LA2)	Rio Largo	Tabuleiro Costeiro	Leste alagoano
Yellow Latosol 3 (LA3)	Teotônio Vilela	Tabuleiro Costeiro	Leste alagoano
Red Latosol - Yellow 1 (LVA1)	Coruripe	Tabuleiro Costeiro	Leste alagoano
Red Latosol - Yellow 2 (LVA2)	Palmeira dos Índios	Pediplane of the Baixo São Francisco	Agreste alagoano
Red Latosol - Yellow 3 (LVA3)	Teotônio Vilela	Tabuleiro Costeiro	Leste alagoano

Source: ZAAL (2023).

Stability of Aggregates

To obtain the aggregate stability of the Oxisols studied, undisturbed samples were collected in the 0-20 cm depth layer. The samples were air-dried, de-torted, passed in an 8 mm sieve and retained in a 4 mm sieve. Subsamples of 100 grams of aggregates were used (Figure 2A), which were saturated by capillary ascension and submitted to wet tamisamento with vertical oscillation for 10 minutes, in the Yoder agitator, equipped with three sets of sieves with a mesh of 2.00; 1,00; 0,500; 0.250 and 0.106 mm, according to the method proposed by Kemper; Rosenau (1986). The aggregates retained in each sieve were transferred to metal containers and conducted to the drying oven at 105° C for 24 hours. The quantification of the content retained in each sieve allowed the determination of the percentage of aggregates by diameter classes, associated with the openings of the meshes. The indexes weighted mean diameter (DMP), geometric mean diameter (GDM) and aggregate stability index of class < 0.25 mm (g) were calculated.

Hydraulic variables

The hydraulic variables used in this research were obtained through simulated rainfall tests according to the methodology described by Meyer; Harmon (1979), with soil samples from Latosols of Alagoas.

The height of the flow slide (h) was obtained by equation (1), derived by Woolhiser; Liggett (1967), and Singh (1983) for kinematic solution of Saint-Venant equations:

$$h = \frac{q}{V} \tag{1}$$

Where:

h = height of the flow blade (m);

q = net discharge per unit width ($m^2 s^{-1}$); v = average flow velocity ($m s^{-1}$).

Froude's number was obtained according to Simons; Senturk (1992), according to equation 2:

$$Fr = \frac{V}{\sqrt{gh}} \tag{2}$$

Where:

Fr = Froude number (dimensionless);

g = acceleration of gravity ($m s^{-2}$).

The kinematic viscosity is variable according to the temperature, and it´s therefore necessary to measure the temperature of the water. Because of this, viscosity was determined as a function of temperature according to the expression given by Julien (1995), as shown in equation 3:

$$v = [1{,}14 - 0{,}031(T - 15) + 0{,}00068(T - 15)^2] \, x \, 10^{-6} \tag{3}$$

v = kinematic viscosity of water ($m^2 s^{-1}$);

T = water temperature (°C).

In determining the Reynolds number, equation 4, proposed by Simons, was used; Senturk (1992), where:

$$Re = \frac{Vh}{v} \tag{4}$$

Where:

Re = Reynolds number (dimensionless).

Rates of breakdown and soil losses

The calculation of soil breakdown rates in midsulci was used equation 5, as presented by Bezerra et al. (2006):

$$Di = \frac{Mss}{ADc} \tag{5}$$

Whereas:

Di = rate of soil breakdown in mid-grooves (kg/m^2);

Mss = disaggregated dry soil mass (kg);

A = plot area (m^2);

Dc = collection duration (s).

Soil losses were obtained through equation 6, as also proposed by Bezerra et al. (2006), where:

$$Ps = \frac{\sum(QCst)}{A} \tag{6}$$

Where:

Ps = soil loss (kg/m^2);

Q = flow (L s^{-1});

Cs = sediment concentration (kg L^{-1});

t = interval between collections (s);

Estimation of soil erodibility in midsulci by simulated rainfall

The determination of soil erodibility in the midsulci was used equation 7, according to the Flanagan WEPP model; Nearing (1995), in conditions of bare soil, freshly prepared and without residues, where:

$$\mathrm{Ki} = \frac{\mathrm{Di}}{\mathrm{I}^2\mathrm{Sf}} \tag{7}$$

Where: Ki = soil erodibility in midgrooves (kg s m^{-4});

Di = maximum rate of soil breakdown in mid-grooves (kg m^{-2} s^{-1});

I = rainfall intensity (m s^{-1});

Sf = correction factor for the slope (dimensionless), given by equation 8 of Liebenow et al. (1990):

$$Sf = 1{,}05 - 0{,}85exp^{-4\,\mathrm{sen}\,\theta} \tag{8}$$

Where: θ = angle of the slope of the ground (degrees).

In the present work the value of Sf é de 0,456, because the slope adopted in the plot was 0,09 m m^{-1}, where the angle of 5,14°.

Estimation of soil erodibility by mathematical models

The soil erodibility factor (Ki) was indirectly verified through the use of three empirical equations, which used chemical, physical and morphological variables of the soil samples for the evaluation. The mathematical models were used in the work of Araújo et al. (2011), and were previously proposed and/or modified by other scientists.

Equation 9 was proposed by Bertoni; Lombardi Neto (2018), based on Middleton (1930), who considers:

$$K = \frac{(\%\ \text{clay dispersed in water})/(\%\ \text{total clay})}{(\%\ \text{total clay})/(\%\ \text{of equivalent humidity})} \qquad (9)$$

The second model used was modified by Lima et al. (1990), which is an adaptation of the Lombardi Neto equation; Bertoni (1975). Equation 10 is:

$$K = \frac{(\%\ \text{silt + clay dispersed in water})/(\%\ \text{silt + total clay})}{(\%\ \text{total clay})/(\%\ \text{of equivalent humidity})} \qquad (10)$$

The third equation used (equation 11), was proposed by Bouyoucos (1935) and described by Bertoni; Lombardi Neto (2010), where the erodibility factor is given by:

$$K = \frac{(\%\ \text{sand}+\%\ \text{silt})/(\%\ \text{clay})}{100} \qquad (11)$$

Statistical analysis

The variables were submitted to analysis using the statistical software R (R Core Team, 2021), generating principal component analysis (PCA) and cluster analyses. For hierarchical multivariate analysis of clusters, it was defined by the visual comparison of dendrograms in which distinct branches are marked with different colors and with evaluation of the trend of data storage and the decision on the number of the cluster examining in cluster and validating the results. For the analyses, some packages were used, such as: FactoMineR, car, corrr, ggcorrplot, multcomp, lattice, PerformanceAnalytics, RColorBrewer and rsm.

Results and discussion

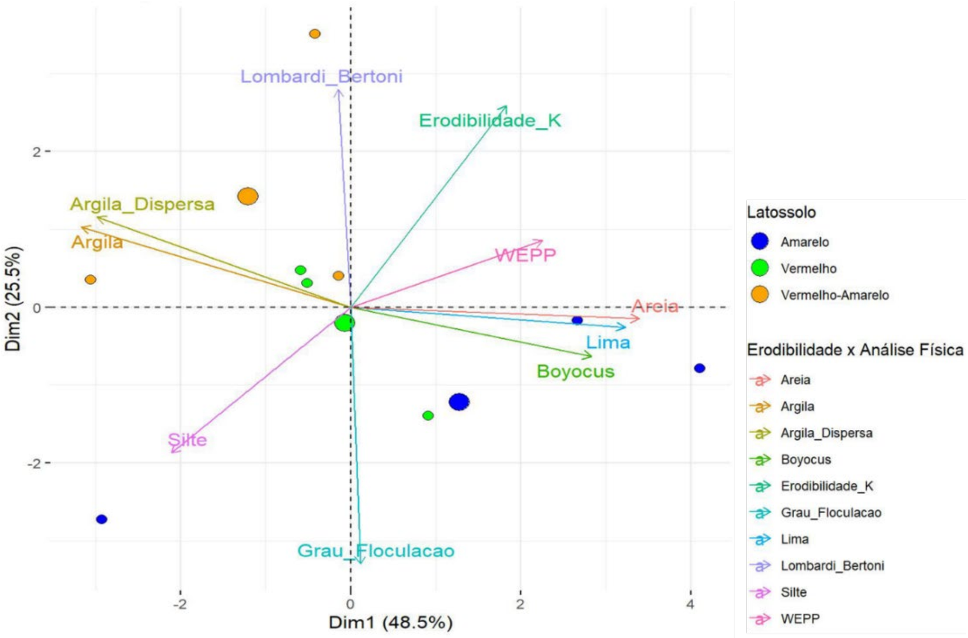
Principal Component Analysis (ACP)

Physical Attributes

Evaluating the physical attributes of the Oxisols in relation to the values of erodiability, it´s possible to observe based on Figure 2 that of the ten variables studied, only the variables sand, Lima; Bouyoucos has large positive factor loadings in dimension 1 (DIM1) and correlation with each other, as observed by the vectors of greater length and closer to the main axis and presence of acute angles between the variables presented. It´s observed that the Yellow Latosol was the most representative in dimension or component 1, thus demonstrating a relationship with these three variables.

Figure 2.

Physical analysis of the main component of the WEPP variables, Lombardi Neto; Bertoni (Lombardi_Bertoni), Lima; Bouyoucos, erodibility factor in Ki midgrooves (Erodibilidade_K), sand, clay, clay dispersed in water (argila_dispersa), degree of flocculation (grau_floculação) and silt in the behavior of the three Latosols of Alagoas in the relationship between the attributes of the physical analysis and the estimation of erodibility in midsulci.



Source: The authors (2023).

With regard to the secondary axis, the variables Lombardi Bertoni and degree of flocculation presented higher vector value and proximity to this axis, and these variables were also related to the Red and Red-Yellow Latosols.

It´s noteworthy that the mathematical models of erodibility estimation proposed by Bouyoucos (1935) and Lima et al. (1990) presented a negative correlation with the variables clay, clay dispersed in water and silt (Figure 3). This negative correlation can be understood by the fact that these important soil attributes are related to the erosive process, such as: crusting, aggregation, porosity, water infiltration and drag of particles and aggregates by the flood, and may thus be contributing to an increase or reduction in erodibility (UEHARA; GILLMAN, 1981; ANGULO, 1983).

Chemical Attributes

Regarding the PCA of the analysis of chemical attributes, we can observe in Figure 4 that the sum of the two main components (PCA1 and ACP2) represent a total variance of 57.2% in the analysis of the sixteen variables studied.

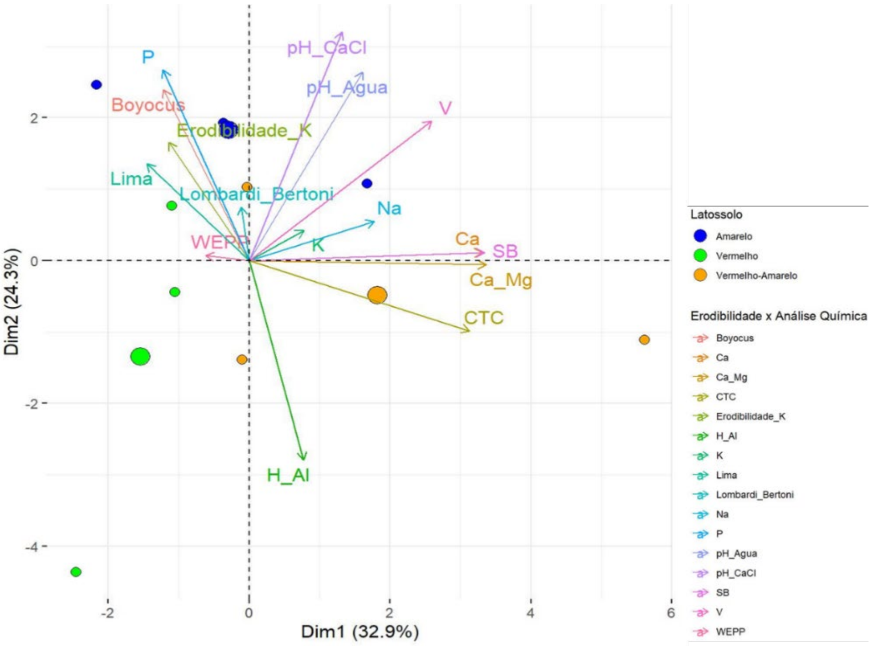
The variables Ca, SB and Ca, Mg showed greater proximity to the main axis and high correlation with each other, in addition to having a relationship with the Red-Yellow Latosol, as well as the CTC variable, which among the four variables is the one with the greatest affinity with this soil suborder.

It´s observed in the graph that the methods of estimating erodibility (Bouyoucos, erodibility k, WEPP, Lima and Lombardi Bertoni) showed a positive correlation with each other and with the macronutrient phosphorus (P), which according to the Institute of Potash and Phosphate (1998) can happen due to the decrease in soil compaction through erodibility, which allows the accumulation and greater availability of phosphorus in these soils. This positive correlation is more evident between the Bouyoucos and P methods, as observed by the approximation of the vector arrows of these variables and by the distance from the secondary axis.

The graph in Figure 3 also shows the existence of a relationship between the variables mentioned above and the Yellow Latosol and a sample of the Red-Yellow Latosol. As for the Red Latosol, no direct relationship of this type of soil with any variable studied can be observed.

Figure 3.

Chemical principal component analysis of the variables WEPP, Lombardi & Bertoni (Lombardi Bertoni), Lima, Bouyoucos, factor erodibility in Ki midsulci (Erodibility K), calcium (Ca), calcium+magnesium (Ca Mg), cation exchange capacity (CTC), potential or total acidity (H Al), potassium (K), sodium (Na), phosphorus (P), pH measured in water (pH water), pH measured in calcium chloride (pH Ca Cl), sum of bases (SB) and saturation by bases (v) in the behavior of the three Latosols of Alagoas in the relationship between the attributes of the chemical analysis and the estimation of erodibility in midsulci.



Source: The authors (2023).

Aggregate Stability

In the principal component analysis (PCA) that evaluates the behavior of the three Latosols of Alagoas (Yellow Latosol, Red Latosol and Red-Yellow Latosol) in the relationship between aggregate stability and the estimation of erodibility in midsulci, it was demonstrated that the Lima erodibility estimation method is the one that most closely approximates the main axis and with the longest vector, and this variable is positively correlated with the variables Bouyoucos and WEPP, where it´s proven through the analysis of the graph that these three variables are related to the Yellow Latosol.

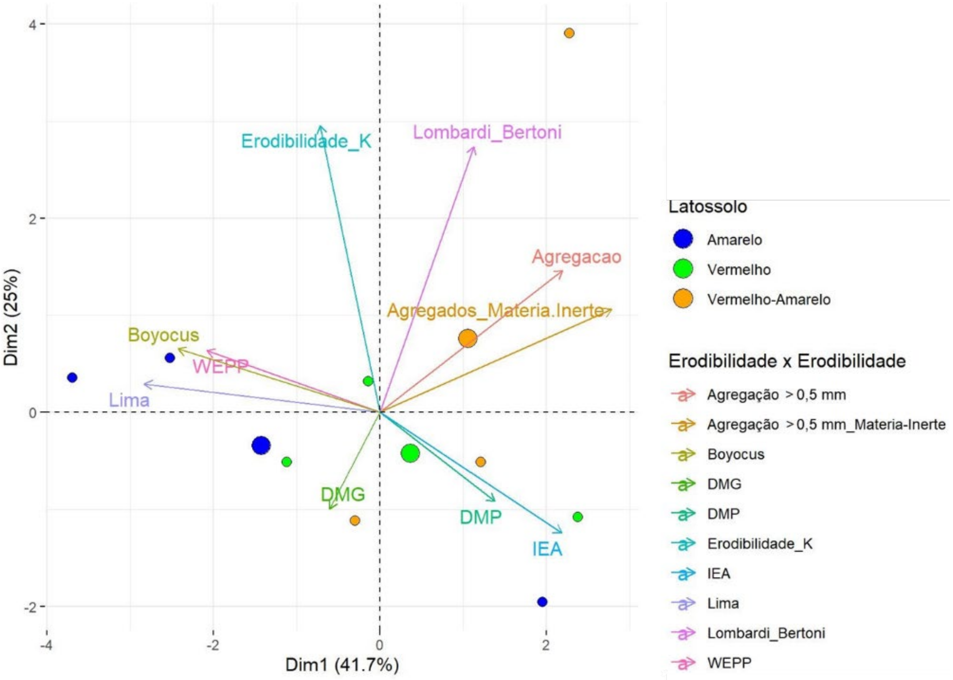
In the secondary axis the variable with the highest vector and relation to this axis is the Erodibility K, which is calculated by the factor erodibility in Ki midgrooves. This variable was also directly related to a Red Latosol sample and a positive correlation with the Lombardi Bertoni variable.

As shown in figure 4, we can see that the variable aggregate stability index (IEA) demonstrates a negative correlation with all methods of estimating erodibility, either to a greater or lesser degree. Allowing the inference that the higher the IEA, the lower the erodibility presented and vice versa, as also proven by Meyer; Harmon (1984), Albuquerque et al. (2000) and Legout et al. (2005) in their studies that evaluated the correlation between these factors.

The Red and Red-Yellow Latosols on average present correlation to a greater degree with the variables DMP and IEA (Red Latosol) and, Mat aggregates. Inert, Aggregation and Lombardi Bertoni (Red-Yellow Latosol).

Figure 4.

Analysis of aggregate stability with a principal component analysis of the variables WEPP, Lombardi & Bertoni (Lombardi_Bertoni), Lima, Bouyoucos, erodibility factor in Ki midgrooves (Erodibilidade_K), % aggregation > 0.5 mm (aggregation), % aggregation > 0.5 mm of inert material (agregados_mat. inert), weighted average diameter (DMP), geometric mean diameter (GDM) and aggregate stability index (IEA) in the behavior of the three Alagoas Oxisols in the relationship between stability of aggregates and the estimation of erodibility in midsulci.



Source: The authors (2023).

Cluster Analysis

Physical Attributes

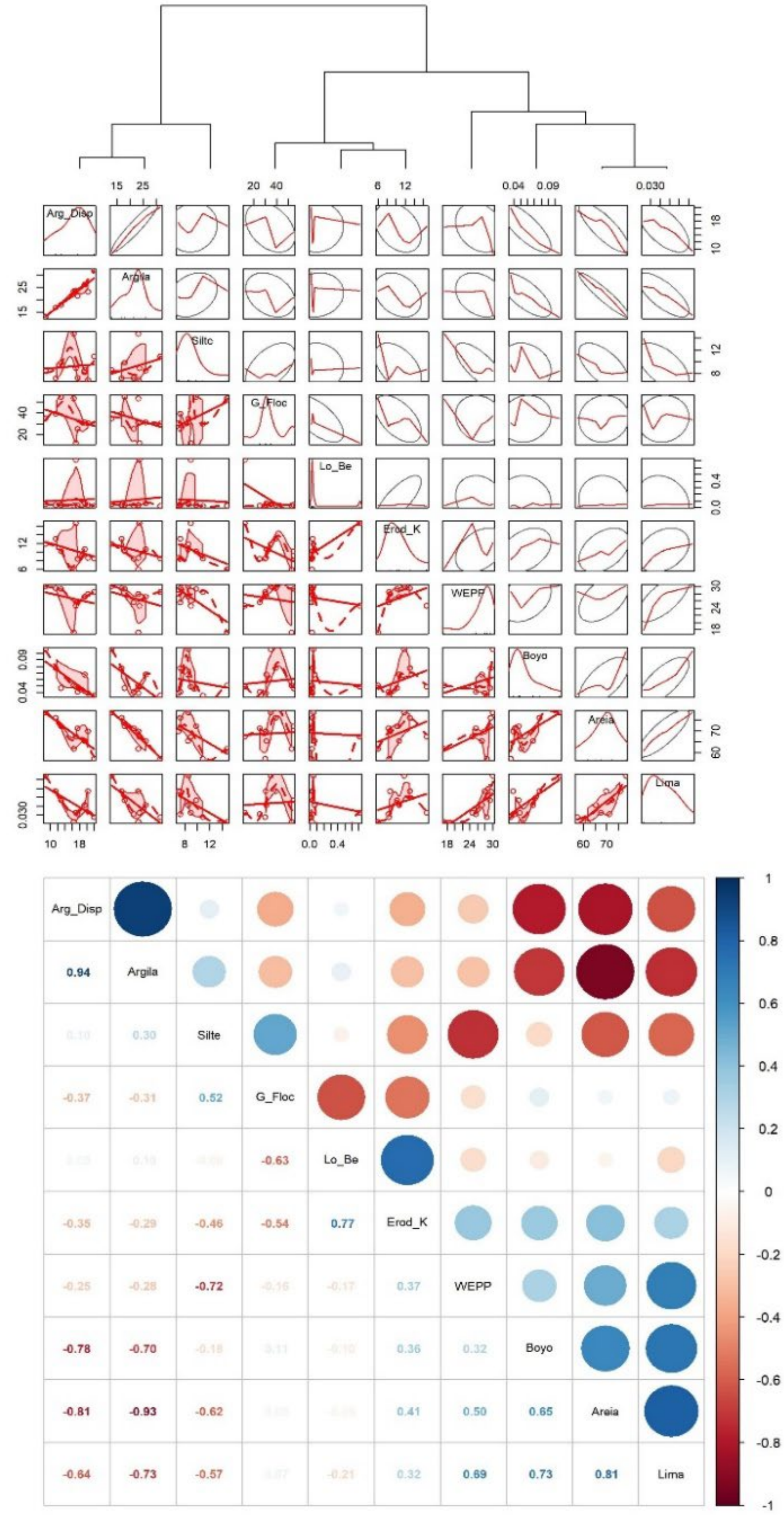
Figure 6 shows the evaluation and quality of fit for the variables WEPP, Lombardi & Bertoni (Lo_Be), Lima, Bouyoucos (Bouyo), erodibility factor in Ki midsulci (Erod_K), sand, clay, clay dispersed in water (Arg disp), degree of flocculation (G Floc) and silt, observed by the correlation between the values of the physical attributes of the soil and the methods of estimating erodibility in midsulci by means of hierarchical cluster analysis, correlation coefficient, dispersion, confidence regions, dendrogram, density estimation and ellipses.

It´s noted (Figure 5) that the dendrogram shows great similarity between six variables studied, and the pairs of variables Arg disp x Argila, Lo Be x Erod_K and Lima x Areia, the latter conglomerate with greater similarity between the three pairs. In order to produce an analysis with satisfactory levels of similarity of clusters and seeking to simplify the number of clusters, the number of 3 main clusters was chosen as the final partition by cutting the dendrogram.

The prediction of correlation metrics shows that the cluster grouping indicates that the best correlations found were between the variables: clay and clay dispersed in water ($r = 0.94$), lime and sand ($r = 0.81$), and between Lo Be and the factor erodibility in midsulci ($r = 0.77$). These strong positive correlations are proven through scatterplots, confidence regions, dendrogram, density estimation, and ellipses.

Figure 5.

Cluster grouping for physical attributes, correlation coefficient, dispersion, confidence regions, dendrogram, density estimation and ellipses of soil physical attribute values and methods of estimating erodibility in midgrooves.



Source: The authors (2023).

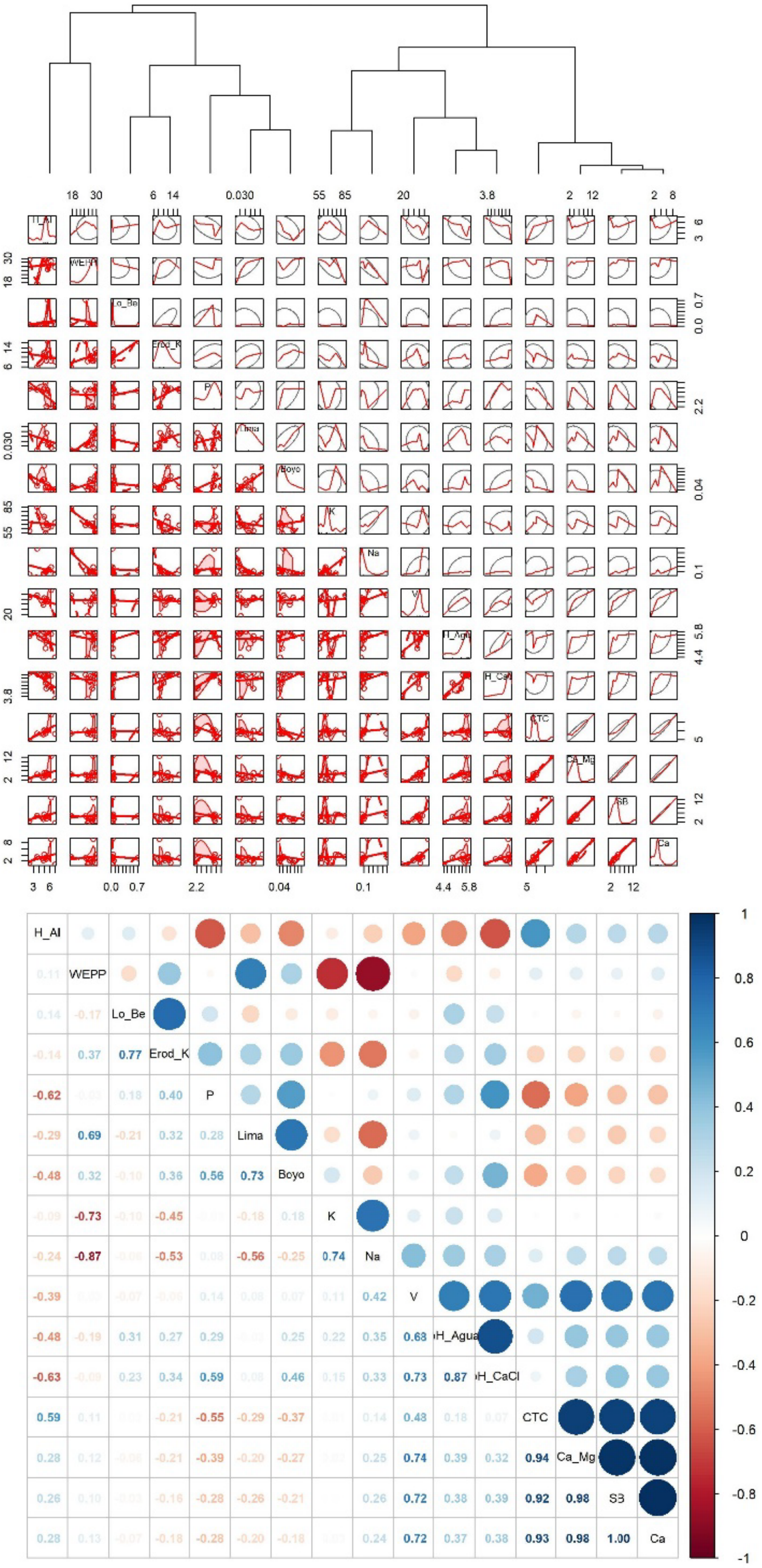
Chemical Attributes

Figure 6 shows the positive and/or negative correlations between the variables studied, with regard to some soil chemical attributes and the methods of estimating erodibility in midsulci. It´s identified that there are positive correlations with values above 90%, as is the case of the correlations between the variables CTC and SB (r = 0.92), Ca and CTC (r = 0.93), Ca_Mg and CTC (r = 0.94), Ca and Ca_Mg (r = 0.98), Ca_Mg and SB (r = 0.98) and finally Ca and SB (r = 1.00). This probably occurs because the variables Ca and Ca_Mg are present in the calculation of the values of the chemical attributes of CTC (effective) and SB. According to the dendrogram, the greatest similarities of clusters were among the factors mentioned above, as observed by the sizes of the vertical lines of these variables arranged in the graph, thus promoting the generation of six groups of direct similarity.

The analysis of cluster clusters also shows that there is a strong positive correlation between the estimators of the factor erodibility in midsulci, as is the case of the Bouyoucos and Lima models (r = 0.73), and this correlation occurred due to the fact that both models use the values of sand, silt and clay in their calculation. The Ki factor, calculated by means of the simulated rainfall test (Erodibilidade_K), obtained expressive similarity with the Lombardi model; Bertoni (r = 0.77). Since the Ki factor is the closest to the real one, it can be affirmed through the analysis that this model is the most assertive to predict the possibility of a given Latosol eroding.

In general, the dendrogram produced in the final section 7 clusters in order of similarity of the clusters.

Figure 6.
Cluster grouping for chemical attributes, correlation coefficient, dispersion, confidence regions, dendrogram, density estimation and ellipses of soil chemical attribute values and methods of estimating erodibility in midsulci.



H_Al														
0.11	WEPP													
0.14	-0.17	Lo_Be												
-0.14	0.37	0.77	Erod_K											
-0.62	-0.03	0.18	0.40	P										
-0.29	0.69	-0.21	0.32	0.28	Lima									
-0.48	0.32	-0.10	0.36	0.56	0.73	Boyo								
-0.09	-0.73	-0.10	-0.45	-0.01	-0.18	0.18	K							
-0.24	-0.87	-0.06	-0.53	0.08	-0.56	-0.25	0.74	Na						
-0.39	0.03	-0.07	-0.06	0.14	0.08	0.07	0.11	0.42	V					
-0.48	-0.19	0.31	0.27	0.29	-0.03	0.25	0.22	0.35	0.63	pH_Agua				
-0.63	-0.09	0.23	0.34	0.59	0.08	0.46	0.15	0.33	0.73	0.87	pH_CaCl			
0.59	0.11	0.02	-0.21	-0.55	-0.29	-0.37	0.01	0.14	0.48	0.18	0.07	CTC		
0.28	0.12	-0.06	-0.21	-0.39	-0.20	-0.27	0.02	0.25	0.74	0.39	0.32	0.94	Ca_Mg	
0.26	0.10	-0.03	-0.16	-0.28	-0.26	-0.21		0.26	0.72	0.38	0.39	0.92	0.98	SB
0.28	0.13	-0.07	-0.18	-0.28	-0.20	-0.18	0.03	0.24	0.72	0.37	0.38	0.93	0.98	1.00

Ca

Source: The authors (2023).

Aggregate Stability

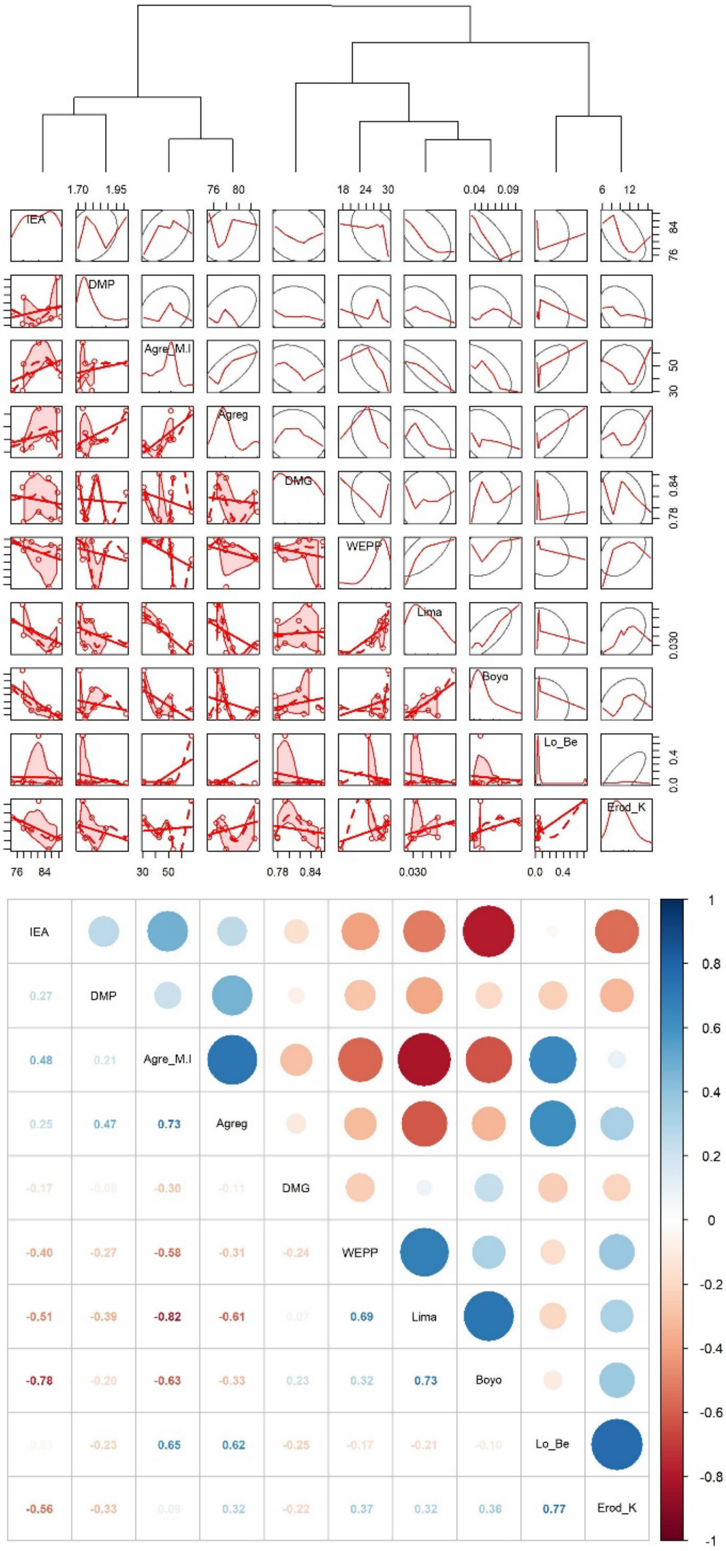
Analyzing Figure 7 it´s possible to verify that the best mathematical method to estimate the erodibility in midgrooves is the Lombardi Neto method; Bertoni (1975), therefore, presents a greater correlation with the variable erodibilidade_K (r = 0.77).

The aggregate stability index (IEA) showed a negative correlation with all methods of assessing erodibility in midsulci, but especially with Bouyoucos (1935) (Boyo) with a correlation value of r = - 0.78. This negative correlation between aggregate stability and susceptibility to erosion was also proven by Wischmeier; Mannering (1969) and Bajracharya et al. (1992).

It´s noteworthy that of all the variables analyzed, the mean geometric diameter (GDM) presented negative correlations with almost all the variables studied, isolating it almost entirely from the other variables, as proven by the dendrogram, where this variable does not present direct similarity with any variable studied. This fact directly influenced the choice of a cluster with 4 conglomerates in the final section, since the distances of the lines along the vertical axis are significant, not allowing a final cut of the lower dendrogram, thus giving evidence to similarity levels of larger clusters.

Figure 7.

Cluster agrupation, correlation coefficient, dispersion, confidence regions, dendrogram, density estimation and ellipses of aggregate stability values and methods of estimating erodibility in midsulci.



IEA									
0.27	DMP								
0.48	0.21	Agre_M.I							
0.25	0.47	0.73	Agreg						
-0.17	-0.08	-0.30	-0.11	DMG					
-0.40	-0.27	-0.58	-0.31	-0.24	WEPP				
-0.51	-0.39	-0.82	-0.61	0.07	0.69	Lima			
-0.78	-0.20	-0.63	-0.33	0.23	0.32	0.73	Boyo		
-0.03	-0.23	0.65	0.62	-0.25	-0.17	-0.21	-0.10	Lo_Be	
-0.56	-0.33	0.09	0.32	-0.22	0.37	0.32	0.36	0.77	Erod_K

Source: The authors (2023).

Final considerations

1. The Aggregate Stability Index has a negative correlation with erodibility.
2. The estimation method of Lombardi Neto & Bertoni (1975) proved to be the most consistent with the method of simulated rainfall estimation of erodibility in midsulci.
3. Multivariate statistics allow a greater understanding of the behavior of correlations between the physical, chemical and stability attributes of aggregates with the erodibility of Latosols from Alagoas.
4. All the variables studied were related to any of the three suborders of soils of Alagoas (Yellow, Red and Red-Yellow Latosol).

REFERENCES

Albuquerque, J. A., Cassol, E. A., Reinert, D. J. (2000). Relação entre a erodibilidade em entressulcos e estabilidade dos agregados. *Revista Brasileira de Ciência do Solo*, 24(1), p. 141-151. https://doi.org/10.1590/S0100-06832000000100016.

Angulo, R. J. (1983). Relações entre a erodibilidade de algumas propriedades de solos Brasileiros. [Dissertação de mestrado em Agronomia, Universidade Federal do Paraná]. https://acervodigital.ufpr.br/handle/1884/27471?show=full

Araújo, F. S., Salviano, A. A. C., Neto, M. R. H. (2011). Estimativa da erodibilidade de latossolos do Piauí. *Scientia Plena*, *7*(10). https://scientiaplena.org.br/sp/article/view/358.

Araujo Filho, J. C. de., Santos, J. C. P. dos., Parahyba, R. da B. V., Oliveira Neto, M. B. de., Barros, A. H. C., Marques, F. A., Amaral, A. J. do. (2020). *Zoneamento agroecológico do estado de Alagoas: levantamento de reconhecimento de baixa e média intensidade dos solos do estado de Alagoas (ZAAL).* Embrapa Solos. https://www.embrapa.br/busca-de-publicacoes/-/publicacao/1124244/zoneamento-agroecologico-do-estado-de-alagoas-levantamento-de-reconhecimento-de-baixa-e-media-intensidade-dos-solos-do-estado-de-alagoas

Bajracharya, R. M., Elliot, W. J., Lal, R. (1992). Erodibilidade entre sulcos de alguns solos de Ohio com base na simulação de chuva de campo. *Soil Science Society of America Journal* , *56*(1), p. 267-272. https://doi.org/10.2136/sssaj1992.03615995005600010041x

Bertol, I., Leite, D., Engel, F.L., Cogo, N. P., González, A. P. (2007). Erodibilidade de um Nitossolo Háplico alumínico determinada em condições de campo. *Revista Brasileira de Ciência do Solo*, *31*, p. 541-549. https://doi.org/10.1590/S0100-06832007000300014.

Bertoni, J., Lombardi Neto, F. (2018). *Conservação do solo* (p. 355). Ícone.

Bezerra, S. A., Cantalice, J. R. B. (2006). Erosão entre sulcos em diferentes condições de cobertura do solo, sob cultivo da cana-de-açúcar. *Revista Brasileira de Ciência do Solo*, *30*, p. 565-573. https://doi.org/10.1590/S0100-06832006000300016.

Bocuti, E. D., Amorim, R. S. S., Santos, T. G., Di Raimo, L. A. D. L., Pereira, H. G. (2019). Erodibilidade entressulcos e sua relação com atributos de solos do Cerrado. Revista de Ciências Agrarias, 42(1), p. 68-78. https://doi.org/10.19084/RCA18130.

Bouyoucos, G. J. (1935). Proporção de argila como critério de suscetibilidade de solos à erosão. *Jornal da Sociedade Americana de Agronomia*. 27, p. 738-741. https://agris.fao.org/agris-search/search.do?recordID=US201301776020.

Flanagan, D. C., Nearing, M. A. (1995). USDA-Water Erosion Prediction Project: Documentação de perfil de encosta e modelo de bacia hidrográfica. *Nserl Rep*, *10*, p. 1-123. https://www.ars.usda.gov/research/publications/publication/?seqNo115=64035.

IBGE – Instituto Brasileiro de Geografia e Estatística. (2020). *Cidades e Estados*. https://www.ibge.gov.br/cidades-e-estados/al/arapiraca.html.

Julien, P. Y. (1995). *Erosion and sedimentation*. Melbourne, Cambridge University Press, 280p.

Kemper, W. D., Rosenau, R. C. (1986). Estabilidade agregada e distribuição de tamanho. *Métodos de análise de solo: Parte 1 Métodos físicos e mineralógicos*, *5*, p. 425-442. https://doi.org/10.2136/sssabookser5.1.2ed.c17.

Legout, C., Leguèdois, S., Le Bissonais, Y. (2005). Aggregate breakdown dynamics under rainfall compared with aggregate stability measurements. *European Journal of Soil Science, 56*(2), p. 225-238. https://bsssjournals.onlinelibrary.wiley.com/doi/10.1111/j.1365-2389.2004.00663.x

Liebenow, A. M., Elliot, W. J., Laflen, J. M. (1990). Interrill Erodibility: Collection and Analysis of Data From Cropland Soils. *Transactions of The Asae,* 33(6), p. 1882-1888. Htttps://doi.org/10.13031/2013.31553.

Lima, J. M., Curi, N., Resende, M., Santana, D. P. (1990). Dispersão do material de solo em água para avaliação indireta da erodibilidade de latossolos. *Revista Brasileira de Ciência do Solo*, 14(1), p. 85-90. https://www.alice.cnptia.embrapa.br/handle/doc/489138.

Lombardi Neto, F., Bertoni, J. (1975). *Erodibilidade de solos paulistas*. Instituto Agronômico. 12p. (Boletim Técnico, 27).

Meyer, L. D., Harmon, W. C. (1979). Simulador de chuva de intensidade múltipla para pesquisa de erosão em taludes. *Transactions of the ASAE*, *22*(1), p. 0100-0103. https://doi.org/10.13031/2013.34973.

Meyer, L. D., Harmon, W. C. (1984). Susceptibility of agricultural soils to interrill erosion. Soil Science Society of America Journal, 48(5), p. 1152-1157. https://doi.org/10.2136/sssaj1984.03615995004800050040x.

Middleton, H. E. (1930). *Propriedades dos solos que influenciam a erosão do solo*. Departamento de Agricultura dos Estados Unidos, 178, 16.

Mota, J. C. A., Alves, C. V. O., Freire, A. G., de Assis Junior, R. N. (2014). Análises uni e multivariadas de indicadores de qualidade física do solo de um Cambissolo do Planalto do Apodi – CE, Brasil. *Soil and Tillage Research*, *140*, p. 66-73. https://doi.org/10.1016/j.still.2014.02.004.

Nunes, M. C. M., Cassol, E. A. (2008). Estimativa da erodibilidade em entressulcos de Latossolos do Rio Grande do Sul. *Revista Brasileira de Ciência do Solo*, *32*, p. 2839-2845. https://doi.org/10.1590/S0100-06832008000700030.

Oliveira, J. B. (2011). *Pedologia Aplicada*. (4ª ed.). FEALQ.

Pragana, R. B., Ribeiro, M. R., Nóbrega, J. C. A., Ribeiro Filho, M. R., Costa, J. A. D. (2012). Qualidade física de Latossolos Amarelos sob plantio direto na região do Cerrado piauiense. *Revista Brasileira de Ciência do solo*, *36*, p. 1591-1600. <https://doi.org/10.1590/S0100-06832012000500023>.

R Core Team (2021) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Saed-Moucheshi, A., Fasihfar, E., Hasheminasab, H., Rahmani, A., Ahmadi, A. (2013). Uma revisão sobre técnicas estatísticas multivariadas aplicadas em agricultura e ciência vegetal. *International Journal of Agronomy and Plant Production*, *4*(1), p. 127-141. https://www.researchgate.net/profile/Armin_Saed.

SANTOS, H. G. dos. (2018). *Sistema brasileiro de classificação de solos*. (5ª ed.). EMBRAPA.

Silva, M. L. N., Curi, N., Ferreira, M. M., Lima, J. M. D., Ferreira, D. F. (1999). Proposição de modelos para estimativa da erodibilidade de Latossolos brasileiros. *Pesquisa Agropecuária Brasileira*, *34*, p. 2287-2298. https://doi.org/10.1590/S0100-204X1999001200016.

Simons, D.B., Şentürk, F. (1992). *Tecnologia de transporte de sedimentos: dinâmica da água e dos sedimentos*. Publicação de Recursos Hídricos. 5(1), 892 p.

Singh, V. P. (1983). Soluções analíticas de equações cinemáticas para erosão num plano II. Precipitação de duração finita. *Avanços em Recursos Hídricos*, *6*(2), p. 88-95. https://doi.org/10.1016/0309-1708(83)90045-3.

Thomaz, E. L, Fidalski, J. (2020). Erodibilidade entresulcos de diferentes solos arenosos aumenta ao longo de uma catena na Formação Arenítica Caiuá. *Revista Brasileira de Ciência do Solo*, *44*. https://doi.org/10.36783/18069657rbcs20190064.

Uehara, G., Gillman, G. (1981). The mineralogy, chemistry and physics of tropical soils with variable charge clays. Boulder: Westview Press. 170p.The mineralogy, chemistry, and physics of tropical soils with variable charge clays. (cabdirect.org).

Wischmeier, W.H, Mannering, JV (1969). Relação das propriedades do solo com a sua erodibilidade. *Soil Science Society of America Journal*, *33*(1), p. 131-137. https://doi.org/10.2136/sssaj1969.03615995003300010035x.

Wischmeier, W. H., Smith, D. D. (1978). *Prevendo perdas por erosão pluvial: um guia para planejamento de conservação* (No. 537). Departamento de Administração da Agricultura, Ciência e Educação.

Woolhiser, D. A., Liggett, J. A. (1967). Fluxo instável e unidimensional sobre um plano - O hidrograma ascendente. *Pesquisa de recursos hídricos*, *3*(3), p. 753-771. https://doi.org/10.1029/WR003i003p00753.