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Tolerance of soil loss by erosion in the western mesoregion of Maranhão

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ABSTRACT

The growing technological advance in agriculture, verified through the introduction of machines, fertilizers, new cultivars, and expansion of agricultural frontiers, has provided, in general, an increase in the average yield of crops due to the rational management of the soil-climate-plant system. However, as the soil is managed without adopting conservationist practices, imbalances and instability occur, constituting serious problems such as desertification, salinization, soil erosion, etc. Thus, this study aimed to determine the soil loss tolerance by erosion in the western mesoregion of Maranhão. The methods used to determine tolerance used effective depth (h), textural ratio (r), textural ratio and clay content in the A horizon, organic matter, and permeability, where the equations for each method were: T= h. r. 1000^{-1} (Method I); T = h. ra. 1000^{-1} (Method II) and T = h. ra. m. P. 1000^{-1} (Method III). The highest soil loss tolerance values were identified in method I (1.95 t ha^{-1} yr^{-1}), then method III (0.76 t ha^{-1} yr^{-1}), and finally, method II (0.67 t ha^{-1} yr^{-1}), observing soil loss tolerance values differed about the method used.

Keywords: Soil management, Environmental conditions, Erodibility.

Tolerância de perda de solo por erosão na mesorregião oeste do Maranhão

RESUMO

O crescente avanço tecnológico na agricultura, verificado através da introdução de máquinas, fertilizantes, novas variedades e expansão de fronteiras agrícolas tem proporcionado, de modo geral, aumento na produtividade média das culturas, devido ao manejo racional do sistema solo-clima-planta. No entanto, à medida que o solo passa a ser manejado sem a adoção de práticas conservacionistas ocorrem desequilíbrios e instabilidade constituindo em sérios problemas como desertificação, salinização e erosão do solo. Desta forma, o objetivo desse trabalho foi determinar a tolerância à perda de solos por erosão na mesorregião oeste do Maranhão (Amazônia Maranhense). Os métodos utilizados para determinação da tolerância foram profundidade efetiva (h), relação textural (r), relação textural e teor de argila no horizonte A, matéria orgânica e permeabilidade, onde as equações, para cada método, foram: T= h. r. 1000^{-1} (Método I); T = h. ra. 1000^{-1} (Método II) e T = h. ra. m. p. 1000^{-1} (Método III). Os maiores valores de tolerância a perda de solo foram identificados no método I (1,95 t ha^{-1} ano^{-1}), em seguida o método III (0,76 t ha^{-1} ano^{-1}) e por último o método II (0,67 t ha^{-1} ano^{-1}), observando que os valores de tolerância de perdas de solo diferiram em relação ao método utilizado.

Palavras-chave: Manejo do solo, Condições ambientais, Erodibilidade.

1. Introduction

Soil is a natural resource that is linked to successful agricultural production. However, indiscriminate use of this resource can intensify natural degradation processes such as erosion, compaction, and contamination. Therefore, for soil management to be based on its potential for use, it is important to know the processes and properties that govern it and to apply techniques that enable its conservation (Lima et al., 2022). The lack of planning for the use of agricultural land associated with excessive grazing, deforestation, soil erosion, microclimate changes, and inadequate management can lead to deterioration in soil quality and productivity (Souza et al., 2023), promoting environmental, social, and economic problems (Brito et al., 2022).

Soil loss is a process that can occur naturally through erosion caused by water or wind agents or through anthropogenic activities such as agriculture, deforestation, mining, and construction (Oliveira et al., 2008). Thus, estimating soil loss plays a key role in establishing sustainable policies based on the location of the area and the factors (climate, topography, soil characteristics, land use, and management practices) that contribute to and can affect soil loss rates (Frozzi et al., 2020).

Estimating soil loss rates usually involves measuring or quantifying soil erosion over time using erosion pins, sediment traps, or runoff plots (Ranieri and El-Robrini, 2012). Soil loss models such as the Universal Soil Loss Equation (USLE) are commonly used to estimate loss rates based on various factors, such as erosivity, soil erodibility, slope and slope length, land use, and conservation practices adopted (Barbosa et al., 2015). According to Oliveira et al. (2008), information on soil loss tolerance due to erosion can be used with the Revised Universal Soil Loss Equation (RUSLE). This is the most widely used method in Brazil, with many studies aimed at determining specific factors for various regions.

Some studies have used models to calculate soil loss tolerance in different regions of Brazil. According to Nunes et al. (2012), soil loss tolerance enables a better choice of soil management systems and reduces erosion. Furthermore, the information can support conservation planning, contributing to the socio-economic development of production (Queiroz et al., 2021). In Maranhão, the main causes of soil erosion are deforestation, excessive grazing, and unsustainable land use practices such as over-cultivation and monoculture (Macedo et al., 2019).

Despite this, little research has addressed soil loss and/or soil loss tolerance in the state. Even so, Martins and Silva (2022) studied the physical and structural properties of the soil in an area under degradation in the region of Balsas, MA, and found that areas with exposed soils are more vulnerable to erosion than areas with vegetation cover. Martins et al. (2020), studying the erosive potential of rainfall in Maranhão, found high rainfall erosivity. Oliveira and Araújo (2020) found urban linear erosion processes in a gully in São Luís, Maranhão.

Thus, the hypotheses of this study were: i) it is possible to use different methods for calculating soil loss tolerance in a mesoregion of the state of Maranhão; ii) the different methods for calculating soil loss tolerance lead to different results, and iii) the application of soil loss tolerance methods for erosion in the western mesoregion of the state of Maranhão is appropriate. Therefore, this study aimed to determine the soil loss tolerance due to erosion in the western mesoregion of Maranhão using different methods.

2. Material and Methods

The study was carried out with 42 soil profiles that were classified up to the third categorical level (Table 1) located in the Western Mesoregion of Maranhão (Figure 1), with data obtained from the Pedology Technical Report of the Ecological Economic Zoning of the State of Maranhão - Amazon Biome Stage (Relatório Técnico de Pedologia do Zoneamento Ecológico Econômico do Estado do Maranhão - Etapa Bioma Amazônico), whose survey was carried out in 2019. Soil profiles were selected in the context of the western mesoregion of Maranhão. Most of the areas chosen were natural areas (forested), and considering the geological (rocks) and geomorphological (relief) features, they were described and collected, following the technical criteria established in the IBGE Technical Manual (2015), using soil mapping as a cartographic basis (IBGE, 2021).

Table 1. Soil classes and representative profiles of the western mesoregion of Maranhão

Soil class	Nº of Profiles
Argissolo Amarelo Distrófico	3
Argissolo Vermelho Amarelo Distrófico	4
Argissolo Vermelho Distrófico	3
Argissolo Vermelho Eutrófico	2
Cambissolo Háplico Distrófico	1
Gleissolo Háplico Distrófico	1
Latossolo Amarelo Distrocoeso	1
Latossolo Amarelo Distrófico	4
Latossolo Vermelho Amarelo	1
Latossolo Vermelho Amarelo Distrófico	4
Luvissolo Crômico Órtico	1
Neossolo Litólico Distrófico	1
Neossolo Quartzarênico Órtico	3
Plintossolo Pétrico Concrecionário	3
Plintossolo Argilúvico Distrófico	7
Plintossolo Háplico Distrófico	3
Total	42

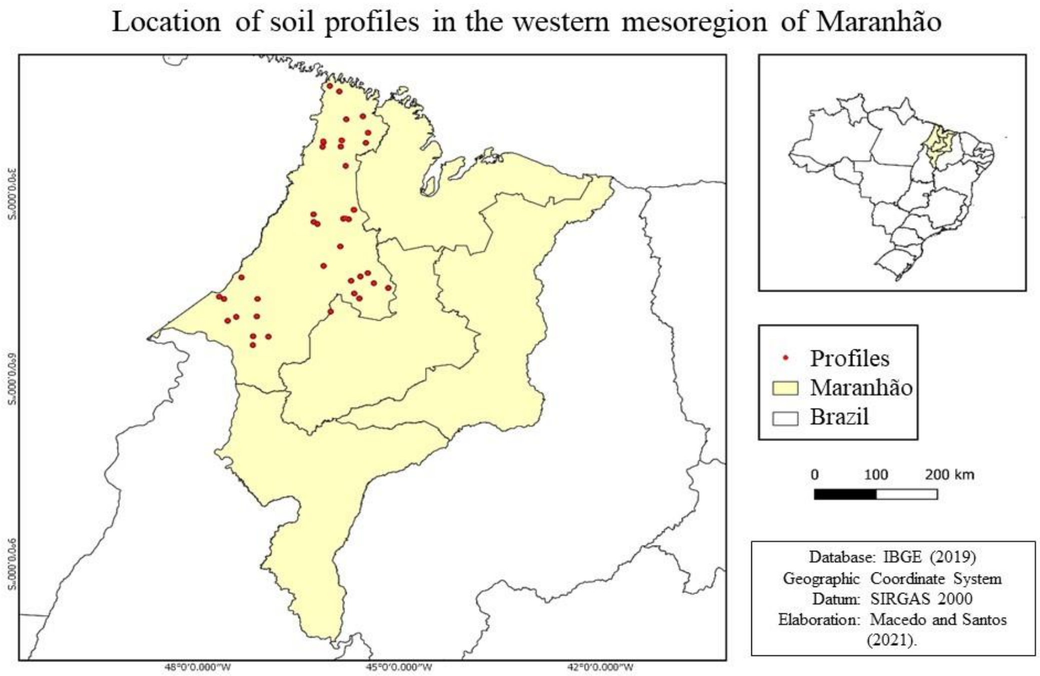

Figure 1. Location of the profiles analyzed in the western mesoregion of Maranhão. Source: Author (2023)

The profiles were georeferenced using GPS equipment and distributed across the study area, as shown in Figure 1. Soil loss tolerance estimates were calculated using three methods: Method I, proposed by Lombardi Neto and Bertoni (1975); Method II, a modification of Method I by Bertol and Almeida (2000); Method III, a modification of the method by Galindo and Margolis (1989). The effective depth of the soil and the textural relationship between the B and A horizons were used, according to the criteria established by Lombardi Neto and Bertoni (1975), as important variables in estimating soil loss tolerance due to water erosion.

The effective depth is the layer favorable to the development of the root system of cultivated plants, considered up to the limit of 1 meter, restricted to the A and B horizons, excluding the B3 horizon (current BC) (Embrapa, 1988). Calculating the textural ratio was impossible in soils without subsurface horizons, making it impossible to calculate soil loss tolerances for some soil classes. The soil loss tolerance was calculated using the expression (Lombardi Neto and Bertoni, 1975):

$$T = h * r * 1{,}000^{-1}$$

where T = soil loss tolerance (mm year^{-1}); h = effective soil depth (mm) limited to 1,000 mm; r = quotient that expresses the effect of the textural relationship between the B and A horizons on the weighting of soil losses (g kg^{-1}), and 1,000 = constant that expresses the period needed to erode a layer of soil 1,000 mm thick, disregarding soil formation during this period, according to the procedure of Lombardi Neto and Bertoni (1975).

The assumption that a soil layer one meter thick is eroded every thousand years, disregarding the natural replacement of soil, explains the procedure of limiting the effective depth of the soil to one meter (1000 mm) when calculating soil loss tolerances (Bertol and Almeida, 2000). For a textural ratio of less than 1.5, the soil loss tolerance of a given profile was obtained by multiplying its effective depth (limited to one meter) by an r-value equal to 1.00.

When the textural ratio was between 1.5 and 2.5, the r value used was 0.75; when it was greater than 2.5, an r value of 0.50 was used. The textural ratio was obtained from the ratio between the average clay content of the B horizon (excluding B3, current BC) and the average clay content of the A horizon.

Method II is a modification of Method I in terms of the limit of intervals in the textural relationship between the B and A horizons and the introduction of the clay content of the A horizon (Table 2) as a variable associated with the textural relationship (Bertol and Almeida, 2000). With the new values for the variable r in Method I, renamed ra, the equation was modified to:

$$T = h * r_a * 1{,}000^{-1}$$

where: T = soil loss tolerance (mm year^{-1}); h = effective soil depth (mm), limited to 1,000 mm; r_a = ratio that jointly expresses the effect of the textural relationship between the B and A horizons and the clay content of the A horizon; 1,000 = constant that expresses the period needed to erode a layer of soil 1,000 mm thick, disregarding the formation of soil during this period, according to the procedure of Lombardi Neto and Bertoni (1975).

Table 2. Textural ratio factor B/A and clay content of the A horizon.

Textural ratio	Clay content (%)		
	< 20	40 -	> 40
<1.5	0.8	0.9	1.0
1.5 – 2.0	0.6	0.7	0.8
> 2.0	0.4	0.5	0.6

Source: Author (2023)

Table 3. Soil permeability effect factor.

Texture	Structure	Permeability
Thin (Clay > or = 35%)	Weak	Slow
	Moderate	Slow
	Strong	Moderate
Medium (15% < or = Clay < 35%)	Weak	Moderate
	Moderate	Moderate
	Strong	Fast
Thick (Sand and sandy loam)	Weak	Moderate
	Moderate	Fast
	Strong	Fast
Slow: 0.85	Moderate: 1.0	Fast: 1.15

Source: Author (2023)

In Method III, in addition to the variables and weighting factors adopted in Method II, two important properties were added from the point of view of erodibility, such as the organic matter content of the soil in the 0-20 cm depth layer and the degree of soil permeability, as suggested by Galindo and Margolis (1989). Method III was used in the version of Galindo and Margolis (1989), according to the equation:

$$T = h * r_a * m * p * 1{,}000^{-1}$$

where T, h, r_a, 1,000 = same definitions as in Methods I and II; m = factor expressing the effect of organic matter in the 0-20 cm layer; p = factor expressing the effect of soil permeability.

Concerning the organic matter content, expressed by the m factor, the following criteria were adopted as proposed by de Galindo and Margolis (1989): (a) for soils with an organic matter content (OMC) > 2%, the thickness of the soil layer was multiplied by the factor 1.15; (b) for OMC contents between 1 and 2%, the thickness of the soil layer was multiplied by a factor of 1.00; (c) for soils with OMC content < 1%, the thickness of the soil layer was multiplied by a factor of 0.85.

The permeability of each horizon of the profiles studied was based on information on the texture and degree of development of the soil structure (Table 3) in the respective horizons obtained from the database (secondary source), according to the methodology of Galindo and Margolis (1989): (a) for rapid permeability, the thickness of the soil layer was multiplied by a factor of 1.15; (b) for moderate permeability, the thickness of the soil layer was multiplied by a factor of 1.00; and (c) for slow permeability, the thickness of the soil layer was multiplied by a factor of 0.85. The soil loss tolerance values obtained by the three methods were compared with each other, between soil orders or classes and within each method, and between methods for all soil orders, using the Tukey test at 5% probability. Analyses of variance and statistical tests were conducted using Sisvar software.

3. Results and Discussion

Table 4 shows the average values of textural ratio and effective depth for the 42 profiles studied. The textural ratio ranged from 0.95 (Latossolo Vermelho Amarelo Distrocoeso) to 4.50 (Plintossolo Argilúvico Distrófico). At the same time, the effective depth had its lowest value with the Neossolo Litólico Distrófico (less than 1 m). In contrast, the highest value, 1.60 m, was found in the Argissolo Amarelo Distrófico, Argissolo Vermelho Distrófico, Latossolo Amarelo Distrófico, Latossolo Vermelho Amarelo Distrófico e o Neossolo Quartzarênico Órtico.

The soil loss tolerance values for methods I, II, and III are shown in Table 5. In general, the highest soil loss tolerance values were found for method I, a behavior also observed by Nunes et al. (2012). However, according to Nunes et al. (2012), the soil loss tolerance values were much higher, probably associated with local conditions (Lense et al., 2019).

Among the soil orders compared using method I, it was found that the Neossolos had the lowest tolerance values (1.17 t ha^{-1} $year^{-1}$), while the Plintossolos had the highest values (3.55 t ha^{-1} $year^{-1}$). Statistically, the Gleissolos and Plintossolos were the ones that tolerated the greatest soil losses when compared to the other orders, probably associated with the position of the relief. In studies by Demarchi and Zimback (2014) in a sub-basin environment in São Paulo, they found that the most weathered pedogenetic classes were those with the greatest tolerance for soil loss.

Method II had the lowest overall average soil loss tolerance (0.67 t ha^{-1} $year^{-1}$) compared to Method I (1.95 t ha^{-1} $year^{-1}$) and Method III (0.76 t ha^{-1} $year^{-1}$) (Table 5). In this method, the Latossolo was the soil class that obtained the highest value, which can be explained by adding permeability, agreeing with the results of Oliveira et al. (2008). According to Pinto et al. (2020), Latossolos, due to their high permeability, high effective depth, and low textural ratio, associated with the predominance of medium/clayey texture, well-developed structure, and considerable organic matter content, contribute to their greater resistance to water erosion.

Table 4. Average values of textural ratio and effective depth of the profiles between the surface and subsurface horizons for the soil classes in the study.

Soil class	Textural ratio	Effective depth
		-- m --
Argissolo Amarelo Distrófico	2.05	1.60
Argissolo Vermelho Amarelo Distrófico	2.09	1.50
Argissolo Vermelho Distrófico	1.73	1.60
Argissolo Vermelho Eutrófico	1.33	1.19
Cambissolo Háplico Distrófico	1.84	1.30
Gleissolo Háplico Distrófico	2.07	1.10
Latossolo Amarelo Distrocoeso	1.28	1.00
Latossolo Amarelo Distrófico	1.73	1.60
Latossolo Vermelho Amarelo Distrocoeso	0.95	1.50
Latossolo Vermelho Amarelo Distrófico	1.27	1.60
Luvissolo Crômico Órtico	1.70	1.40
Neossolo Litólico Distrófico	1.25	0.38
Neossolo Quartzarênico Órtico	1.41	1.60
Plintossolo Pétrico Concrecionário	1.81	1.35
Plintossolo Argilúvico Distrófico	4.54	1.50
Plintossolo Háplico Distrófico	2.98	1.20

Source: Author (2023)

Table 5. Average values of tolerance to soil loss by erosion (t ha^{-1} $year^{-1}$) for the main soil orders in the western region of Maranhão, estimated by different methods.

Soil Order	Method I*	Method II**	Method III***
	------------------------ t ha^{-1} $year^{-1}$	-------------------	
Argissolo	1.87 b	0.67 ab	0.78 ab
Cambissolo	1.84 b	0.70 ab	0.68 b
Gleissolo	2.07 a	0.60 ab	0.59 b
Latossolo	1.42 b	0.82 a	0.91 a
Luvissolo	1.70 b	0.70 ab	0.93 a
Neossolo	1.17 b	0.65 b	0.76 ab
Plintossolo	3.55 a	0.56 b	0.67 b
Average	1.95 a	0.67 b	0.76 b
CV	8.71 %	6.71 %	5.12%

*Method I (Lombardi Neto and Bertoni, 1975); Method II (Bertol and Almeida, 2000); Method III (Galindo and Margolis 1989). Source: Author (2023).

The results for method III are shown in Table 5. It was observed that Latossolos (0.91 t ha^{-1} $year^{-1}$) and Luvissolos (0.93 t ha^{-1} $year^{-1}$) were the classes with the highest soil loss tolerance values, while Cambissolos (0.68 t ha^{-1} $year^{-1}$) and Gleissolos (0.59 t ha^{-1} $year^{-1}$) had the lowest results and were therefore more vulnerable to erosion. According to Nunes et al. (2012), the content of organic matter and the degree of permeability, based on structure, as well as the textural relationship and effective depth, contributed to the Latossolos and Luvissolos showing greater tolerance to soil loss compared to the other orders studied.

When all the methods were compared, method I was found to have statistically higher soil loss tolerance values than the other methods (II and III) (Table 5). According to Oliveira et al. (2008), the method with the lowest tolerance for soil loss tends to be the suggested method, as the limits are the strictest for losses to minimize the erosion process. Among the soil classes studied, regardless of the method used, it was observed that the Neossolos had statistically lower soil loss limit values. Hence, they are less tolerant to erosion, while the Latossolos had the highest soil loss tolerance, consistent with their attributes (Table 5).

According to Oliveira et al. (2008), the rate of soil erosion in a given region or property and knowledge of the tolerance value for soil loss will indicate the need to adopt management mechanisms and techniques that reduce erosion losses to maintain the sustainability of the production system.

4. Conclusions

The highest soil loss tolerance values were identified in a method I (1.94 t ha^{-1} year^{-1}), followed by method III (0.76 t ha^{-1} year^{-1}), and finally, method II (0.67 t ha^{-1} year^{-1}). The highest soil loss tolerance value was found for Plintossolos (Method I), while the lowest was for the same soil class in Method II.

Under the study conditions, the best method for calculating soil loss tolerance estimates was Method II, as it had the lowest loss tolerance value for the soil classes studied. The non-inclusion of clay content in the first method and, consequently, the direct textural ratio applied to the calculation may cause significant variation compared to the other methods, given that the values with the highest textural ratio also had the highest soil loss tolerance values.

Authors' Contribution

Larissa Thais dos Santos de Macedo, Ligiéria Alves dos Santos, and Marcelino Silva Farias Filho conceived and designed the study; Larissa Thais dos Santos de Macedo, Ligiéria Alves dos Santos and Marcelino Silva Farias Filho acquired, analyzed, and interpreted the data; Flávio Pereira de Oliveira and Milton César Costa Campos contributed to the writing of the manuscript; and Romária Gomes de Almeida and Robson Vinício dos Santos contributed to the critical revision of the intellectual content.

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