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Sediment Yield Equation by Sheet Erosion on Soil Slope for a Semiarid Region

by

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Abstract

The relationship among the rate of sheet erosion loss E, slope length L, rainfall intensity I, slope S_0 and soil detachability parameter α is expressed in the form of $E = \alpha L^{\beta_1} I^{\beta_2} S_0^{\beta_3}$, and α, β_1, β_2 and β_3 are determined by applying a runoff-erosion model for hypothetical plots. The experimental data obtained in nine field plots with different vegetal cover conditions in northeastern Brazil are used to test the proposed equation. The simulation results and a comparison among the results for different types of vegetal cover are presented.
Keywords : sheet erosion, soil loss, bare surface, vegetal cover

1. Introduction

Sediment yield from soil slopes by heavy rainfall depends mainly on the slope length L, the rainfall intensity I, the slope S_0 as well as on the soil characteristics including the condition of vegetal surface. The empirical regression equations between sediment yield and these factors based on large amount of observed data seem to be a good tool to predict rates of sheet erosion. Even if they cannot give an estimate of the yield of individual particle classes, the empirical regression curves can be very useful to estimate the total sediment yield. Musgrave [1)], in 1947, reported on the results of analyses of soil-loss measurements for several storms occurring on fractional-acre plots in the United States. The results of his study gave a relationship among the soil loss E and the factors L, I and S_0 in the form of $E = \alpha L^{\beta_1} I^{\beta_2} S_0^{\beta_3}$, where α is the coefficient depending mainly on the vegetation condition of soil surface and on soil characteristics, and β_1, β_2 and β_3 are the constant exponents.

In the present study, this kind of relationship is proposed for the sediment yield of a typical semiarid region of northeastern Brazil, using field data and simulated data by a runoff-erosion model. The determination of a regression equation is firstly made using hypothetical plots, which is simulated with calibrated parameters of the runoff-erosion model proposed by Santos *et al.* [2)] for a Brazilian semiarid region. Then, in order to test the proposed equation, data from nine experimental plots located within the semiarid region of northeastern Brazil are used. The nine plots have different conditions of vegetal cover, which enable us to study the effect of the land management on the total sediment yield.

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2. Test Field

The Experimental Watershed of Sumé has been studied since 1972 [3] by SUDENE (Superintendency of Northeast Development) and ORSTOM (French Institute of Scientific Research for the Development in Cooperation) to get data about runoff and sediment yield caused by heavy rainfall in natural field. It has four micro-basins with areas between 0.5 to 1 ha, nine experimental plots with area of 100 m^2, one sub-basin with 10 km^2 operated by natural rainfall and several micro-plots with 1 m^2 operated by simulated rainfall. The surface conditions as well as the slope for each either micro-basin or experimental plot are different. The data for Experimental Watershed of Sumé were resumed by Srinivasan and Galvão [4].

Santos *et al.* [2] have been studying one of these micro-basins and they had calibrated the main parameters of a runoff-erosion model [5] for the basin. The nine experimental plots from which data are used in the present study to test the proposed equation by the simulation for hypothetical plots are 4.55 m width by 22.5 m length (100 m^2), and their mean slope, vegetal cover condition and year of installation are given in Table 1. The same conditions for the land management and vegetation were kept for the plots 1 and 4, and plots 2 and 3 for the comparison among the results with different slopes.

Table 1. Characteristics of the plots with 100 m^2.

Plot No.	Mean Slope (%)	Vegetal Cover	Year of Installation
1	3.8	bare soil	1982
2	3.9	dead vegetal cover	1982
3	7.2	dead vegetal cover	1982
4	7.0	bare soil	1982
5	9.5	native *caatinga*	1982
6	4.0	cactus (vertical tillage)	1983
		corn	1989
7	4.0	cactus (contoured tillage)	1983
		bean	1989
8	4.0	bare and revolved soil	1986
9	4.0	new *caatinga* (1981)	1986

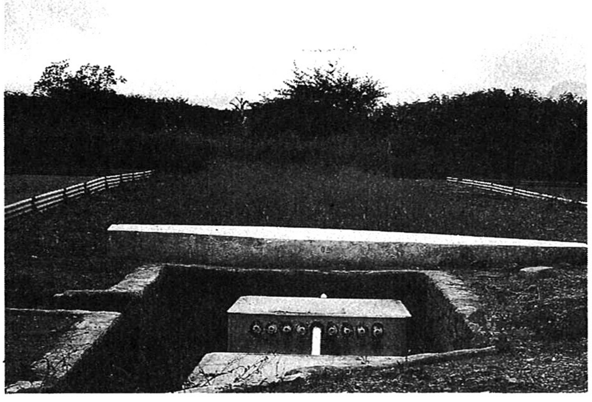

Photo 1 Plot 2 with dead vegetal cover.

Photo 2 Plot 6 with corn under vertical tillage.

In the bare plots (plots 1 and 4) the vegetation was removed when it was reaching 5 cm high. The plots with dead vegetal cover (plots 2 and 3) had their vegetation cut when it was reaching 20 to 25 cm high, but the dead vegetation was not removed from the plots. The plots 6 and 7, with cactus, were cleaned when the vegetation was reaching 5 cm high. The plot 8 was kept constantly without vegetation and the soil was revolved. The plots with native vegetal cover (plots 5 and 9) did not have any human intervention. In order to study the effect of soil erosion by other cultures, the cactus in plots 6 and 7 were removed in 1989 before the rainy season, and corn and bean were planted instead at the beginning of the rainy season using the tillage method which is used in the region, in order to evaluate the runoff and erosion yield from the plots. The corn and bean were chosen because they are the cultures most cultivated in that region. Typical surface conditions for plots 2 and 6 are shown in Photos 1 and 2, respectively.

3. Data

1) Simulation for hypothetical plots

In the present study, hypothetical plots are simulated by the runoff-erosion model with the proposed parameters [2] to determine the exponents of the regression equation, β_1, β_2 and β_3 for the predicting rates of sheet erosion. The hypothetical plots are 30, 100 and 300 m in length, 4, 10 and 20% in slope with unit width. These nine hypothetical plots with saturated soil and under constant rainfall of 5, 15 and 45 mm/hr give a set of 27 data which are used to determine the exponents of predicting rates of sheet erosion equation.

The runoff-erosion model used here is the numerical runoff-erosion model WESP (Watershed Erosion Simulation Program) [5], in which erosion of land surface soil and sediment transport are caused by overland flow and the flow is analyzed based on the kinematic wave approximation. The parameters in the model had been proposed by Santos *et al.* [2] to a micro-basin located in Brazilian semiarid region with a representation of 10 element division. The parameters in the model proposed before are K_R = 2.1 kg·m/N$^{1.5}$·s, K_I = 5.1 x 10^8 kg·s/m^4 and N_s = 0 mm/hr, where K_R is a soil detachability factor for shear stress, K_I is a coefficient to measure soil detachability by rainfall impact and N_s is the soil moisture-tension parameter. Fig. 1 shows an example of the sediment hydrograph simulated for a hypothetical plot with 10% slope. This figure shows that the sediment yield became constant after 13 minutes. In this paper, this constant sediment yield will be discussed.

Figs. 2, 3 and 4 show the relationships between sediment yield E and the rainfall intensity I, slope length L and slope S_0, respectively. It can be seen that the sediment yield changes linearly with rainfall intensity, slope length and slope on the logarithmic scale paper.

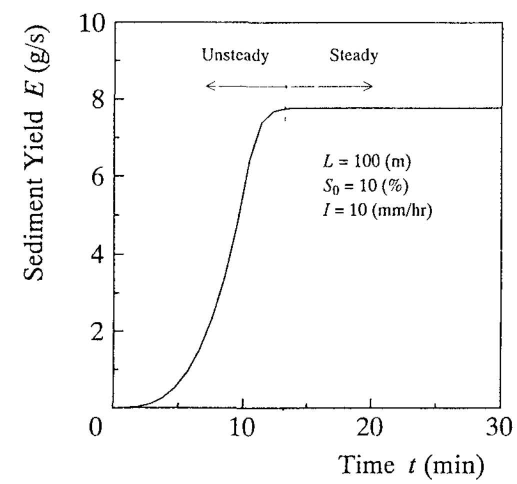

Fig. 1 Example of simulated sediment hydrograph.

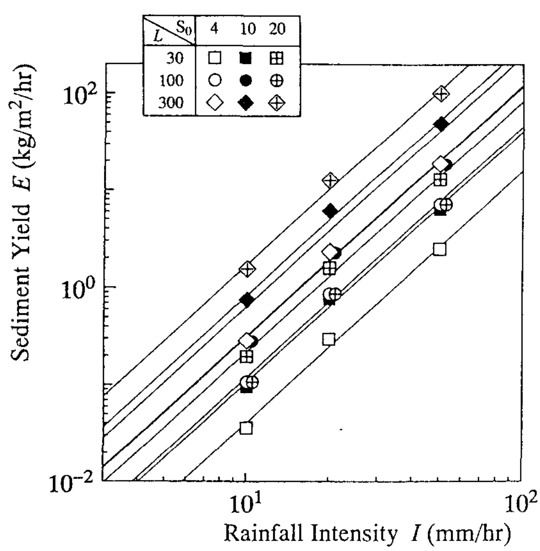

Fig. 2 Simulated relationship between sediment yield E and rainfall intensity I.

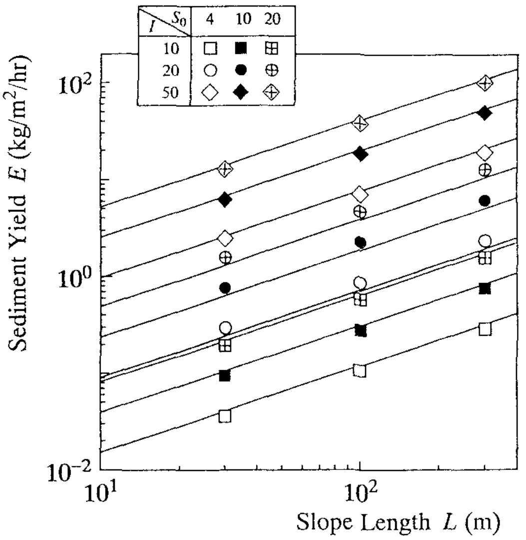

Fig. 3 Simulated relationship between sediment yield E and slope length L.

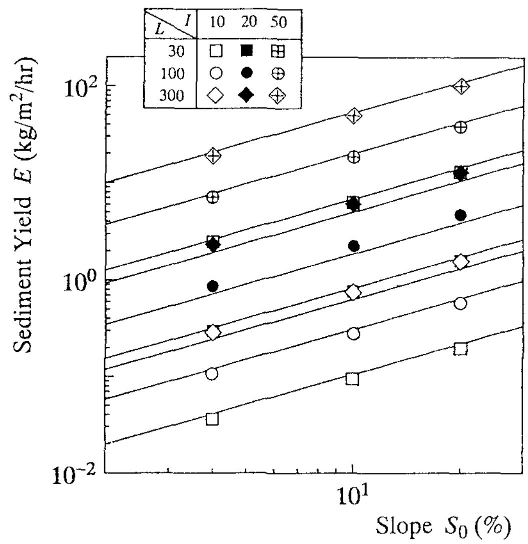

Fig. 4 Simulated relationship between sediment yield E and slope S_0.

2) Experimental field plots

Several rainfall events were chosen between 1987 and 1988 based on the Santos *et al.* [2] work. The relationship between observed runoff depth L_o and observed rainfall depth R_o is shown in Figs. 5 and 6 for the plots without and with vegetal cover, respectively. It can be seen that when the rainfall depth increases the runoff depth increases as well, but for the plots with vegetal cover there are more events with small runoff depth, i.e., less than 0.1 mm. Figs. 7 and 8 show the relationship between the observed sediment yield E_o and the rainfall intensity I, also for the plots without and with vegetal cover, respectively It is clearly observed that when the soil protection is minimum the erosion increase, and the best land protection seems to be either natural vegetation (*caatinga*) or dead cover.

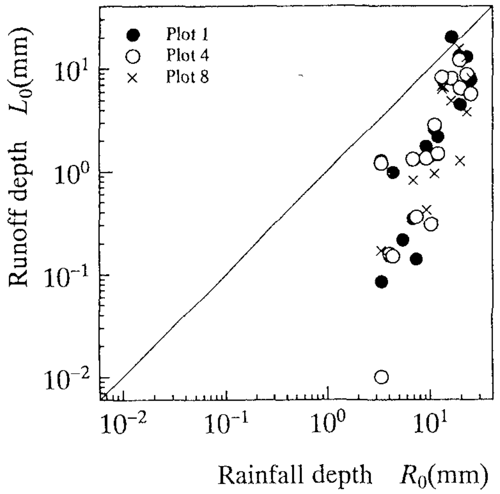

Fig. 5 Relationship between observed runoff depth L_o and observed rainfall depth R_o for the plots with bare soil.

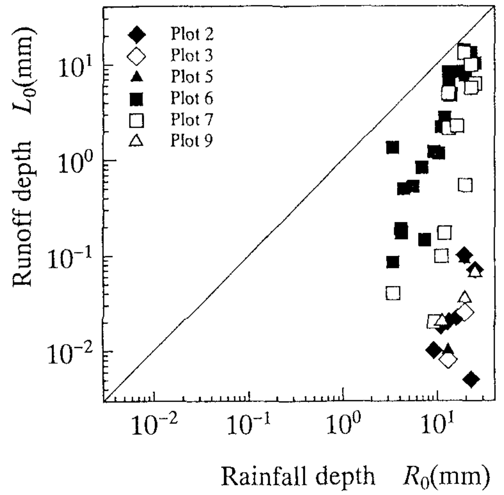

Fig. 6 Relationship between observed L_o and observed rainfall depth R_o for the plots with vegetal cover.

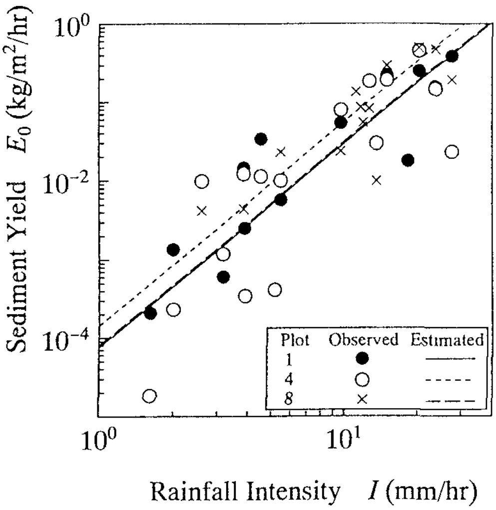

Fig. 7 Relationship between observed sediment yield E_0 and rainfall intensity I for the plots with bare soil.

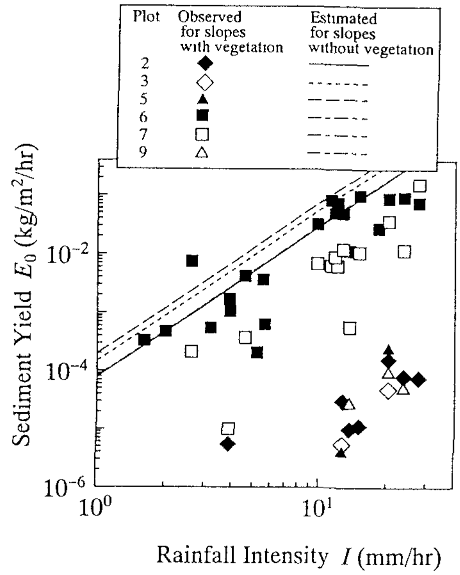

Fig. 8 Relationship between observed sediment yield E_0 and rainfall intensity I for the plots with vegetal cover.

4. Regression Equation

1) Determining the coefficients

Musgrave [1] reported on the results of analyses of soil-loss measurements for some 40,000 storms occurring on fractional-acre plots in the United States. The results of that study indicate that soil loss E varies in accordance with the following relationship:

$$E = \alpha L^{\beta_1} I^{\beta_2} S_0^{\beta_3} \qquad (1)$$

where α is the inherent erodibility of the soil and a cover parameter, β_1, β_2 and β_3 are exponential constant numbers, L is the plot length, S_0 is the slope, and I is the rainfall intensity.

The exponents β_1, β_2 and β_3 in this paper are obtained using the least squares approximation for the data from the hypothetical plots. The approximation is shown by solid straight lines in Figs. 2, 3 and 4. Then, the following equation is proposed:

$$E = 1.19\times10^{-6} L^{0.9} I^{2.59} S_0^{1.04} \qquad (2)$$

where E is in kg/m^2/hr, L in m, I in mm/hr and S_0 in percent.

However, if the effective rainfall intensity r_e is used instead of I, the equation becomes:

$$E = 1.91\times10^{-5} L^{0.9} r_e^{1.91} S_0^{1.04} \qquad (3)$$

where r_e is given by $i_e = I - f$ and f ($\approx$5) is the final infiltration rate in mm/hr.

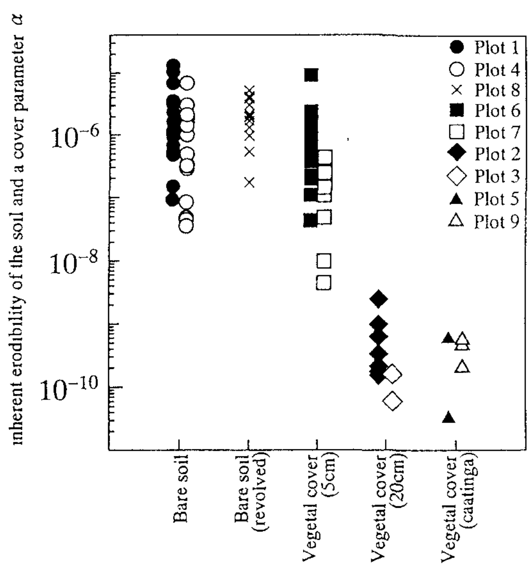

Fig. 9 Relationship between inherent erodibility of soil α and the vegetal cover conditions.

2) Testing the proposed equation

The above equation can be now applied to the nine experimental plots in order to test its applicability. The simulation results for Eq. (2) using the data for nine experimental plots are shown by the lines in Figs. 7 and 8. The equation was determined from hypothetical plots which do not have vegetal cover. It can be seen from these figures that when the soil is protected by some type of vegetation the sediment yield order for this region decreases around 10^{-2}, and among the plots with vegetation the best vegetal cover is the native vegetation and the worst one is cactus in vertical tillage. This is also why the data of the experimental plots 6 and 7, which have cactus, follow the line for the estimation using Eq. (2).

Fig. 9 shows the relationship between the inherent erodibility of the soil α and the vegetal cover conditions. It can be observed that the order for the parameter α to a bare plot is between 10^{-6} and 10^{-8}, but for a plot with *caatinga* (native vegetation) the order becomes 10^{-8} up to 10^{-10}.

5. Conclusions

An equation for predicting rates of sheet erosion is obtained from hypothetical plots with semiarid conditions. In order to test the new proposed coefficients nine experimental plots located in Brazilian semiarid area with different conditions of vegetal cover are used. The following conclusions are obtained:

1) When the soil is protected by some type of vegetation the sediment yield order for this region decreases around 10^{-2}, and among the plots with vegetation the best vegetal cover is the native vegetation and the worst one is cactus in vertical tillage.

2) The order for the erodibility parameter α to a bare plot is between 10^{-6} and 10^{-8}, but for a plot with *caatinga* (native vegetation) the order becomes 10^{-8} up to 10^{-10}.

3) The equation for predicting rates of sheet erosion for this specific area can be assumed as:

$$E = 1.19\times10^{-6} L^{0.9} I^{2.59} S_0^{1.04} \quad \text{or} \quad E = 1.91\times10^{-5} L^{0.9} r_e^{1.91} S_0^{1.04}$$

where E is in kg/m^2/hr, L in m, I and r_e in mm/hr, and S_0 in percent.

The applicability of this equation seems to be acceptable by using nine experimental plots, which are located within a semiarid area of northeastern Brazil.

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