

Division - Soil Use and Management | Commission - Soil and Water Management and Conservation

Water Erosion in Different Slope Lengths on Bare Soil

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ABSTRACT: Water erosion degrades the soil and contaminates the environment, and one influential factor on erosion is slope length. The aim of this study was to quantify losses of soil (SL) and water (WL) in a Humic Cambisol in a field experiment under natural rainfall conditions from July 4, 2014 to June 18, 2015 in individual events of 41 erosive rains in the Southern Plateau of Santa Catarina and to estimate soil losses through the USLE and RUSLE models. The treatments consisted of slope lengths of 11, 22, 33, and 44 m, with an average degree of slope of 8 %, on bare and uncropped soil that had been cultivated with corn prior to the study. At the end of the corn cycle, the stalk residue was removed from the surface, leaving the roots of the crop in the soil. Soil loss by water erosion is related linearly and positively to the increase in slope length in the span between 11 and 44 m. Soil losses were related to water losses and the Erosivity Index (EI_{30}), while water losses were related to rain depth. Soil losses estimated by the USLE and RUSLE model showed lower values than the values observed experimentally in the field, especially the values estimated by the USLE. The values of factor L calculated for slope length of 11, 22, 33, and 44 m for the two versions (USLE and RUSLE) of the soil loss prediction model showed satisfactory results in relation to the values of soil losses observed.

Keywords: soil loss, water loss, USLE, RUSLE.

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INTRODUCTION

Water erosion is the main factor of soil degradation since it impoverishes the place of origin of erosion and pollutes the environment outside of that place, especially water resources. Rainfall erosion is influenced by rainfall, soil, relief, soil cover, and management and conservation practices, including the stages of detachment, transport, and deposition that occur concomitantly (Ellison, 1947; Wischmeier and Smith, 1978; Renard et al., 1997).

Rain is the active agent in rainfall erosion and the magnitude of its influence depends on its intensity, duration, and volume, which is reflected in erosivity. The soil is the passive agent and its susceptibility to erosion depends on its intrinsic characteristics, expressed by erodibility. In untilled soil, without surface cover and without conservation practices, soil erosion depends predominantly on erosivity, erodibility, and on the particular conditions of soil relief (Wischmeier and Smith, 1978; Renard et al., 1997).

The relief factor is represented by the length, the degree of slope, and the shape of the slope, with remarkable influence on water erosion, since it is an energy factor that maximizes surface runoff. The effect of slope length on erosion occurs through an increase in the volume and the speed of runoff, resulting in increased capacity of the runoff to disaggregate and transport sediments (Bagarello and Ferro, 2010).

The effect of slope length on SL is not yet sufficiently understood. Research results on this topic are different and even contradictory since intrinsic characteristics of the soil, type of use, cropping system, and management of soil and crops influence this relation (Lal, 1988). Zingg (1940) observed a three-fold increase in SL upon doubling slope length, whereas Laflen and Saveson (1970) demonstrated that SL increased linearly with increasing length. Bertoni et al. (1972) noted an increase in SL of around 1.5 times upon doubling slope length, a ratio also observed by Wischmeier and Smith (1978). According to Rejman et al. (1999), SL decreased with increasing slope length, whereas Silva and De Maria (2011) observed practically insignificant SL in slope lengths of 25, 50, and 75 m. They could not, therefore, establish a relation between these two variables. These studies were carried out under natural rainfall conditions on a plot scale in various locations and rainfall regimes, with different types of land use and soil management practices, different plants and crop residues, and variable steepness of terrain, which partially explains the diversity of the results. However, in general, in bare and uncovered soil, SL increased with length of slope.

Factors that influence erosion are represented and constitute the structure of the erosion prediction model in the USLE and RUSLE versions, widely used to predict average SL on an annual basis (Foster et al., 1977; Wischmeier and Smith, 1978), whose formula is as follows:

$$A = R K L S C P \quad \text{Eq. 1}$$

in which A = average soil loss ($\text{Mg ha}^{-1} \text{ yr}^{-1}$); R = rainfall erosivity factor ($\text{MJ mm ha}^{-1} \text{ h}^{-1} \text{ yr}^{-1}$); K = soil erodibility factor ($\text{Mg ha h ha}^{-1} \text{ MJ}^{-1} \text{ mm}^{-1}$); L = length of slope factor (dimensionless); S = degree of slope factor (dimensionless); C = soil cover and management factor (dimensionless); and P = practice of conservationist support factor (dimensionless).

In the USLE and RUSLE, the L factor is calculated according to the following general equation:

$$L = \left(\frac{\lambda}{22.1} \right)^m \quad \text{Eq. 2}$$

in which λ = slope of any length, m; 22.1 = standard slope length of the plot, m; and m = exponent related to the steepness of the terrain (0.5 for slope $\geq 0.05 \text{ m m}^{-1}$; 0.4 for slope from 0.035 m m^{-1} to 0.045 m m^{-1} ; 0.3 for slope from 0.01 m m^{-1} to 0.03 m m^{-1});

and 0.2 for slope $<0.01 \text{ m m}^{-1}$) in the USLE. In the RUSLE, the exponent m is also dependent on the slope. It is obtained using the equation:

$$m = \frac{\beta}{1 + \beta} \quad \text{Eq. 3}$$

in which β = ratio between erosion in the rill and erosion interrill. In soil conditions moderately susceptible both to erosion in rill and to erosion interrill, β is calculated by the following equation:

$$\beta = \frac{\left(\frac{\text{sen}\theta}{0.0896}\right)}{[3(\text{sen}\theta)^{0.8} + 0.56]} \quad \text{Eq. 4}$$

in which θ = slope angle.

Modification of the model to the RUSLE version, with inclusion of the value of β for calculation of the m exponent, resulted in an increase in the predictive ability of the RUSLE in relation to the USLE, especially on slopes up to a length of approximately 100 m (Renard et al., 1997).

Based on the above, the following hypotheses were formulated: in bare soil, the relation between slope length and soil loss is linear; soil losses are related to water losses and the Erosivity Index (EI_{30}), while water losses are related to the rain depth; soil losses are underestimated by the USLE and RUSLE compared to the values observed in the field; and the L factor of the USLE and modified L factor of the RUSLE result in a satisfactory estimate of soil loss.

The aim of this study was to quantify soil losses and water losses experimentally in the field, assess soil losses using the USLE and RUSLE models, and relate the soil loss values estimated by the USLE and RUSLE with the values observed in the field for different slope lengths.

MATERIALS AND METHODS

This study was conducted under natural rainfall conditions on a plot scale at $27^{\circ} 49' \text{ S}$ and $50^{\circ} 20' \text{ W}$ and 923 m altitude in Lages, Santa Catarina, Brazil. The weather is the Cfb type in the Köppen classification system according to Wrege et al. (2011), with erosive rainfall totaling $1,533 \text{ mm}$ and annual erosivity totaling $5,033 \text{ MJ mm ha}^{-1} \text{ h}^{-1}$ (Schick et al., 2014a). The soil is classified as a *Cambissolo Húmico Alumínico léptico* (Santos et al., 2013), a Humic Cambisol, in according to the criteria of the IUSS/WRB (2006), with clayey texture and a siltstone substrate, whose erodibility is $0.0175 \text{ Mg ha h ha}^{-1} \text{ MJ}^{-1} \text{ mm}^{-1}$ (Schick et al., 2014b).

In 2012 the ground was tilled a number of times with plow and harrow to incorporate 5 Mg ha^{-1} of dolomitic limestone and 300 kg ha^{-1} of formulated fertilizer 5-20-10 (N-P-K). In November, beans were sown manually and harvested in April 2013, followed by one plowing and one harrowing and then the soil remained fallow until July, at which time one more plowing and two harrowings were done. In November, corn was sown, without fertilizer, with the aid of a "saraquá" (manual seeder), and it was harvested in May 2014. Stalk residue was removed from the soil surface. Over these conditions, the plots that would define the treatments were set up.

The experiment consisted of eight plots, each with dimensions of 2 m width and different lengths down the slope, depending on the treatment. Each plot was bounded at the sides and top by galvanized sheets of $2 \times 0.2 \text{ m}$, driven into the soil to a depth of around 0.1 m. At the lower end, a runoff collector system was placed, consisting of a trough to receive the eroded material from the plot, which was connected by a PVC pipe to a sedimentation box located 6 m below, with 310 L, 500 L, 750 L, or 1,000 L capacity, according to the area of the plot.

Four treatments (T) were evaluated in two field replications, consisting of different slope lengths with varying degrees of slope, due to topographical variation of the ground, as follows: T1 - slope length of 11 m and average degree of slope of 0.084 m m^{-1} ; T2 - slope length of 22 m and an average degree of slope of 0.082 m m^{-1} ; T3 - slope length of 33 m and average degree of slope of 0.077 m m^{-1} ; and T4 - slope length of 44 m and average degree of slope of 0.076 m m^{-1} . The soil was kept without cultivation and without plant cover during the study.

Collection of runoff in the field and processing of samples in the laboratory to calculate SL and WL were made according to Cogo (1978) from July 2014 to June 2015 in 41 erosive rainfalls.

The R factor for both versions of the model (USLE and RUSLE) was obtained by multiplication of total kinetic energy by the maximum intensity in 30 min, called the erosivity index (EI_{30}). To obtain this index in daily rainfalls, erosive rainfalls were rated manually in segments of uniform intensity and recorded on spreadsheets. Subsequently, kinetic energy was calculated as reported by Wischmeier and Smith (1958), according to equation 5:

$$E = 0.119 + 0.0873 \log I \quad \text{Eq. 5}$$

in which E = kinetic unitary energy, $\text{MJ ha}^{-1} \text{ mm}^{-1}$; and I = rainfall intensity, mm h^{-1} .

This equation is applicable to rainfall intensities of up to 76 mm h^{-1} . Above that threshold, the kinetic energy unit of the rainfall is considered constant at $0.2832 \text{ MJ ha}^{-1} \text{ mm}^{-1}$.

The soil K factor was calculated by the ratio between the value of the SL observed in the standard 22-m-length plot and the value of the R factor (EI_{30}) of the rains in the experimental year for the USLE and RUSLE.

The values of the L factor for the USLE and RUSLE were calculated according to equation 2; the exponent m of equation 2 for the RUSLE was calculated according to equation 3, and the values of β in equation 3 were calculated according to equation 4.

The values of the C (soil cover and management) and P (conservation practice) factors were considered equal to one (1) since the soil was kept without cultivation and surface cover and no conservation practices were adopted in the year of the experiment.

Due to variation in the degree of slope within each plot and among plots, we calculated the average S factor (degree of slope of the terrain factor) for each plot, as well as the S factor of the standard degree of slope of the USLE and RUSLE (0.09 m m^{-1}), as proposed by Wischmeier and Smith (1978) and Renard et al. (1997).

For the USLE, the S factor was calculated using the following equation:

$$S = 0.065 + 4.56 \text{ sen}\theta + 65.41 (\text{sen}\theta)^2 \quad \text{Eq. 6}$$

in which S = steepness factor; and θ = slope angle.

To calculate the S factor of the RUSLE the following equation was used:

$$S = 10.8 \text{ sen}\theta + 0.03 \quad \text{Eq. 7}$$

For final adjustment of the SL values, a correction factor (F_c) was calculated based on the S factor calculated for the standard plot by equation 5, according to the following formula:

$$F_c = \frac{S \text{ } 0.09 \text{ mm}^{-1}}{\text{Average S of the plot}} \quad \text{Eq. 8}$$

The SL values of each plot were corrected to the standard slope of 0.09 m m^{-1} ; to do so, the values observed in the field were multiplied by the F_c , calculated by equation 8.

The SL and WL data by water erosion were initially analyzed in regard to normality through the “Shapiro-Wilk” test and then subjected to analysis of variance; when the treatments differed, the average values were compared by the Tukey test ($p \leq 0.05$), using Assisat 7.7 Beta (Silva and Azevedo, 2016). Graphical relationships were made: soil loss (SL) \times water loss (WL); SL \times EI_{30} ; WL \times rain depth (RD); L factor of the USLE \times SL observed; L factor of the RUSLE \times SL observed; SL estimated by the USLE \times SL observed; and SL estimated by the RUSLE \times SL observed; and SL estimated by the USLE \times SL estimated by the RUSLE.

RESULTS AND DISCUSSION

Losses of water and soil through erosion

The increase in water loss (WL) by surface runoff was linear with increasing rain depth (RD) ($p \leq 0.01$) (Figure 1a), as reported by Barbosa et al. (2012), Amaral et al. (2014), and Bertol et al. (2014). According to Bertol et al. (2014), the increase in RD results in an increase in the volume and speed of runoff and, therefore, in the erosive power.

There was an increase in SL values with an increased EI_{30} of the rains ($p \leq 0.05$) (Figure 1b), with greater dispersion of points than was seen in figure 1a. The points located above the linear regression line indicate that some rains with low EI_{30} values caused high SL values. The points below the line mentioned, show high EI_{30} rains that caused low SL. One of the reasons for this may be the water content in the soil prior to the rainfalls, a variable depending on the interval between rains. According with Istok and Boersma (1986), water content in the soil is a determining factor in the variation of water infiltration in the soil and, therefore, a factor in the variation of runoff and soil loss by erosion. Although the variation in water content in the soil has not been quantified, its effect in modifying SL can be more expressive than that of EI_{30} considering individual rainfalls, according to observations made by Eltz (1977). Furthermore, the observed dispersion can be explained by temporal variation in the rainfall pattern that determined its erosivity, as shown by the data of Schick et al. (2014b).

The erosive potential of rain (EI_{30}) is associated with the shearing energy generated by runoff from the soil and the impact of raindrops (Wischmeier and Smith, 1958). In the condition of bare soil without cultivation, the absence of protection on the soil allows the erosive power of the rain to strengthen its capacity to produce erosion. Therefore, under the condition of bare and uncultivated soil, as was the case in this study, the WL explained the SL ($p \leq 0.05$) (Figure 2), which was more than could occur under conditions of cultivated soil covered by crop residue, as observed by Schick et al. (2016).

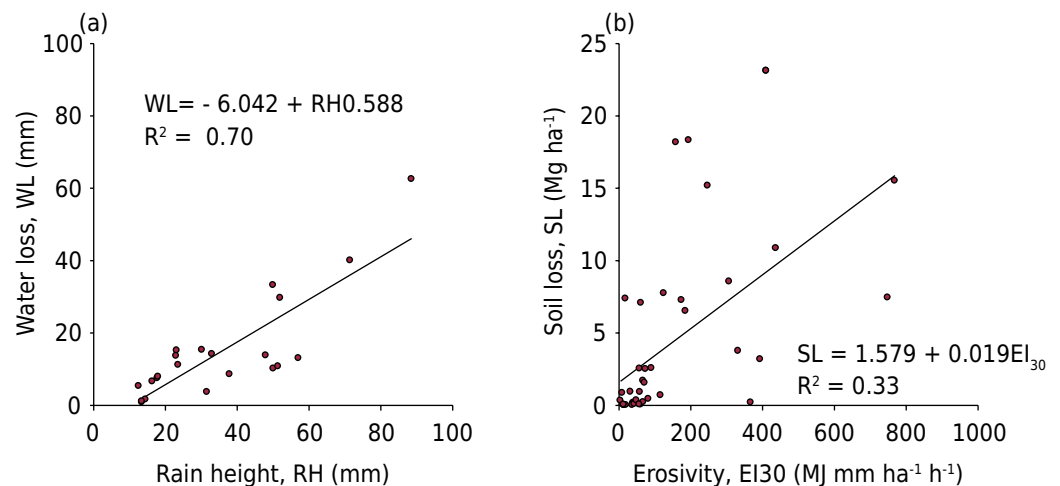


Figure 1. The relation between (a) values of water loss (WL) and rain height (RH) ($p < 0.01$) and (b) values of soil losses (SL) and erosivity (EI_{30}) ($p < 0.05$) (individual values of each variable and average of the treatments).

On bare soil, the impact of raindrops acts on the surface, disaggregates the soil, facilitates formation of a surface seal during the rain and evolves into a crust, causing greater water loss through evaporation (Duley, 1939; Tackett and Pearson, 1965). Soil crusting was visually observed by the authors during the experimental period, but was not quantified. Several studies confirm the occurrence of sealing and crusting of the surface by the action of rain and/or runoff under various management conditions, especially on bare soil (Reichert et al., 1994; Reichert and Norton, 1995; Lado et al., 2004; Le Bissonnais et al., 2005; Rosa et al., 2013).

The SL per unit of area did not vary statistically among treatments (Table 1) showing only a tendency to increase with an increase in slope length, similar to results obtained by Bagarello and Ferro (2010) and in disagreement with Bertoni et al. (1972) and Wischmeier and Smith (1978). This tendency of increase can be observed in figure 3a. The theoretical line of adjustment indicates that in the length of 44 m of terrain, the SL increased 45.5 Mg ha^{-1} (regression coefficient = 1.455), in the average of the ramp.

Duplication of the slope length from 11 m to 22 m led to an increase of 9.2 % in SL in Mg ha^{-1} (Table 1), which was lower than the increase reported by Bertoni et al. (1972) and Wischmeier and Smith (1978). For those authors, upon doubling the length of the slope, soil losses are expected to increase an average of 50 %, ranging from 20 to 80 %. Furthermore, according to Wischmeier and Smith (1978), an increase in SL from the increase of slope length should result in a ratio, in which the value of the regression coefficient (b) ranges from 0.2 to 0.8, with an average of 0.5. The increase in erosion with the length of slope is explained by the greater erosive power of surface runoff, determined mainly by the increase in the volume and speed of runoff.

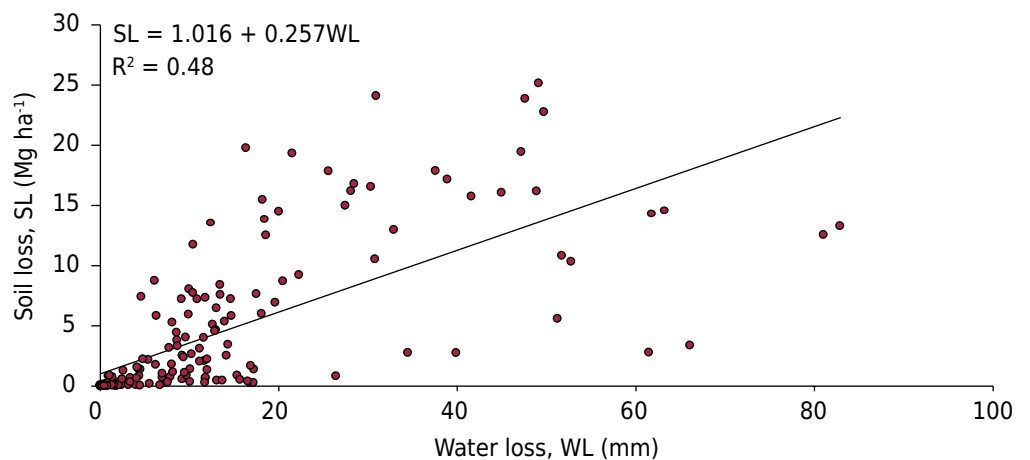


Figure 2. Relation between soil losses (SL) and water losses (WL) (individual values of each variable and average of replicates) ($p < 0.05$).

Table 1. Values of total soil losses in the different treatments obtained in the period from July 4, 2014 to June 18, 2015 and expressed in weight per unit of area and in weight for each slope length studied (average of replications)

Treatment	Soil loss	
	Mg ha^{-1}	Mg
11 m	153	0.36 c
22 m	167	0.82 bc
33 m	183	1.32 b
44 m	201	1.93 a
CV (%)	18	12

Means values followed by different letters in the column differ statistically from each other by the Tukey test ($p \leq 0.05$).

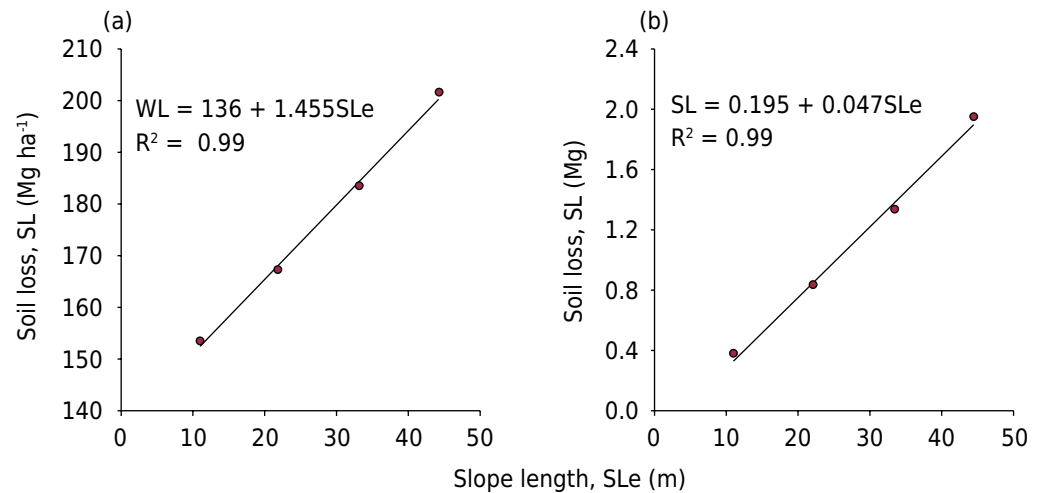


Figure 3. Relation between soil losses (SL), weight \times area (a) and weight (b) and slope lengths (SLe) (total values per treatment) ($p < 0.01$).

Studies done before and after Wischmeier and Smith (1978) confirmed that there is a potential link between the increase in soil weight lost per unit of area and the increase in the length of the slope. By doubling the length of the slope, Zingg (1940) observed a threefold increase in total soil loss. Bertoni et al. (1972) found an increase of 1.4 and 1.6 times in SL when doubling the slope length from 25 to 50 m and from 50 to 100 m, respectively, with degree of slope between 6.5 and 7.5 % and average rainfall of 1,300 mm annually. In studies conducted in natural rainfall conditions on bare soil, Lal (1984) observed an increase in SL with an increase in slope length. Akesson and Singer (1984) reported that the SL ranged from 51 Mg ha⁻¹ in a slope length of 2.4 m to 144 Mg ha⁻¹ in a slope length of 14.7 m.

In other research studies under natural rainfall conditions, this tendency was not confirmed. With slope lengths of 0.25, 0.4, 1.0, 2.0, 5.0, 11, 22, 33, and 44 m in bare and uncultivated soil condition, Bagarello and Ferro (2010) observed that the SL did not vary with the length of the slope in 40 erosive rainfall events over 10 years. The explanation of these authors was that the increase in slope length had a moderate effect in increasing the erosion in the interrill and an appreciable effect on reduction of rill erosion. Thus, the relation found between the SL and the length of slope, plain and simple, under the conditions evaluated was not enough to explain the potential relation published by Wischmeier and Smith (1978). In studying slope lengths of 5, 10, and 20 m for four months, Rejman et al. (1999) found that the SL decreased with an increase in slope length.

Considering only the total weight of soil lost in each slope length studied (Table 1), the variation in SL was statistically significant among treatments ($p \leq 0.05$), from 0.36 Mg in the treatment with slope length of 11 m to 1.93 Mg in the treatment of 44 m. Doubling the slope length from 11 to 22 m increased SL 2.28 times, while doubling the length from 22 to 44 m increased the SL 2.35 times. This increase is confirmed in figure 3b. The theoretical line of adjustment indicates that at the length of 44 m of terrain, the SL increased 4.7 Mg (regression coefficient = 0.047) in the average of the ramp considering the eroded area in each treatment, i.e., 22 m² in T1, 44 m² in T2, 66 m² in T3, and 88 m² in T4.

The SL values observed in the field, calculated in terms of soil loss per unit of area (Mg ha⁻¹) facilitated comparison with other studies in the literature. However, the loss per unit of area conceals the real differences between the treatments. Thus, it appears that in this study, this data should be presented as the total weight of soil lost in each length of slope.

The treatment of 22 m slope length (standard length for the USLE) exhibited SL of 167 Mg ha⁻¹ (Table 1) under erosivity of 6,066 MJ mm ha⁻¹ h⁻¹. Schick et al. (2014b), working with data from 20 years of an experiment in the same soil as this study, calculated SL

of 85.3 Mg ha⁻¹ yr⁻¹ under erosivity of 4.883 MJ mm ha⁻¹ h⁻¹, likewise for a treatment on a standard plot of the USLE. Therefore, the SL observed in 22 m of length was 2.18 times greater than the historical mean for the region obtained by these authors. This difference is explained as follows: in the study of Schick, the soil underwent conventional tillage (one plowing, two harrowings) twice a year; in addition, the erosivity that occurred between 2014 and 2015 was 20 % greater than the historical average. Moreover, since it was the first year of erosion assessment in this study, the soil had a large amount of sediment disaggregated by the treatments prior to setting up the study, facilitating transport by runoff, greater than the average erosion over 20 years obtained by Schick et al. (2014b). According to these authors, as soil erosion progresses over time, the SL decreases because the same erosive energy of the rain encounters a layer of soil more resistant to erosion.

Likewise under the soil conditions found in the standard plot of the USLE, Beutler et al. (2003) found SL of 71.16 Mg ha⁻¹ yr⁻¹ in a *Latosolo Vermelho* (Oxisol) under erosivity of 11,005 MJ mm ha⁻¹ h⁻¹, while Silva et al. (2009) obtained SL of 175 Mg ha⁻¹ yr⁻¹ in a *Cambissolo Háplico* (Inseptisol) with annual erosivity of 4,865 MJ mm ha⁻¹ h⁻¹. This demonstrates the wide variation in SL due to variations mainly from soil type and rainfall patterns.

The SL tolerance established for the soil used in this study was 9.6 Mg ha⁻¹ yr⁻¹ (Bertol and Almeida, 2000). The SL values for the treatments of 11, 22, 33, and 44 m were 16, 17, 19, and 20 times greater than that tolerance, respectively, demonstrating that bare soil should be avoided.

Soil loss exhibited wide numeric variation between months of the year and between treatments; it was 0.01 Mg ha⁻¹ in August 2014 in the slope length of 11 m and 56.3 Mg ha⁻¹ in January 2015 in the length of 44 m, according to the EI₃₀, which ranged from 14 to 1032 MJ mm ha⁻¹ h⁻¹ among the respective months (Table 2).

In September and June, the SL showed a statistical difference ($p \leq 0.05$) among treatments. The WL ranged from 0.3 mm in August 2014 in the 11-m treatment to 112.9 mm in January 2015 in the 44-m treatment according to the RD that ranged from 23 to 193 mm between the respective months. There was a statistical difference ($p \leq 0.05$) in the WL only in April. Numerically, temporal variation of SL was 563 times for a variation of 74 times in EI₃₀, while for WL, the temporal variation was 376 times for a variation of 8 times in the RD, demonstrating that the SL depended much more on the EI₃₀ than the

Table 2. Values of erosivity (EI₃₀), soil loss (SL), rain depth (RD), and water loss (WL) obtained from July 2014 to June 2015 and annual total (T), in different treatments (average of replications)

Month	EI ₃₀ MJ mm ha ⁻¹ h ⁻¹	SL (Mg ha ⁻¹)				CV %	RD mm	WL (mm)				CV %
		11 m	22 m	33 m	44 m			11 m	22 m	33 m	44 m	
Jul	446	0.6	0.5	0.2	0.4	86.8	90	7.2	6.3	6.3	8.3	72.01
Aug	14	0.01	0.02	0.03	0.04	74.83	23	0.3	0.4	0.5	0.6	62.85
Sep	351	14.6 b	16.7 ab	19.5 ab	22.8 a	9.6	144	29.2	35.2	50.5	52.6	34.03
Oct	909	17.2	19.3	20.1	20.7	10.2	167	57.5	46.7	65.9	64.5	29.71
Nov	498	20.2	25.5	25.2	28.2	26.7	133	38.8	41.7	60.1	60.7	27.46
Dec	267	21.7	18.9	19.0	18.2	10.9	113	30.6	36.1	47.2	46.1	37.91
Jan	1,032	42.0	41.8	47.7	56.3	30.6	193	79.2	83.0	109.9	112.9	26.70
Feb	598	10.6	12.9	11.5	19.1	21.3	100	31.8	26.8	32.3	32.1	41.80
Mar	895	12.2	10.8	13.8	8.9	36.9	121	31.1	25.8	29.4	29.4	39.18
Apr	553	9.9	13.5	11.1	11.4	31.5	103	25.7 b	35.5 ab	57.2 a	55.9 ab	16.00
May	116	0.7	0.7	1.2	1.05	80.2	51	13.8	8.0	8.8	7.5	76.57
Jun	389	3.0 c	6.0 bc	13.0 ab	13.7a	21.0	112	46.3	64.4	96.8	96.7	31.97
T	6,066	153.1	167.1	182.8	201.4	-	1,349	392.0	410.2	565.4	567.6	-

⁽¹⁾ Means values followed by different letters in the column differ statistically from each other by the Tukey test ($p \leq 0.05$).

WL depended on the RD. This temporal variation in SL and WL was normal, due to the influence of climate on the characteristics of the rains, which determined their depth and erosivity, and to the temporal variability of water content in the soil, due to the interval between rains and to variation in climate. Lower variation of WL in comparison to SL is in accordance with what has been observed in studies on water erosion under various conditions (Schick et al., 2000; Beutler et al., 2003; Cogo et al., 2003; Schick et al., 2014) due to limits on water infiltration in the soil according to its characteristics.

The months of October 2014 and January 2015 concentrated 32 % of the annual EI_{30} and 27 % of the annual RD, and in those months, SL was equivalent to 19 % and WL to 16 % of the annual total, in the average of the treatments (Table 2). These values are similar to those reported by Schick (2014) and Schick et al. (2014b), who found that there is a close relationship between the SL and the EI_{30} and between the WL and the RD in bare soil conditions in an experiment at this same location. Thus, these two months are problematic in terms of soil and water conservation in the area of research because they concentrate most of the erosion due to the greater erosive potential of the rains on an annual basis.

The treatment in which the slope length was 11 m had WL equivalent to 29 % of the RD, considering the annual total, followed by 30 % in the treatment of 22 m, 42 % in that of 33 m, and 42 % in that of 44 m. Zingg (1940), in a compilation of data from various experiments conducted over 20 years with simulated rain, found that WL decreased with an increase in slope length, which was also verified by Lal (1983). A smaller increase in WL in longer slopes was observed by Silva and De Maria (2011). According to the author, the reduction in the rate of increase in water loss per unit of area can be explained due to greater possibility of water infiltration into the soil and/or evaporation on longer slopes, in which there is also greater variation of the degree of slope of the terrain compared to the shorter ones.

Estimation of soil loss through erosion by the USLE and RUSLE

During the experimental period, total rainfall was 1,349 mm (Table 2), resulting from 41 erosive rains, with an absolute value of the EI_{30} index of 6,066 $MJ\ mm\ ha^{-1}\ h^{-1}\ yr^{-1}$ (Tables 2 and 3). Schick et al. (2014a), studying the historical series of rainfall for 24 years for the same location, found an average annual number of erosive rainfalls of 51, 1,279 (mm) total rainfall, and EI_{30} index of 5,033 $MJ\ mm\ ha^{-1}\ h^{-1}\ yr^{-1}$). Therefore, even with 20 % fewer erosive rains in this study than in the work of Schick, the depth and the EI_{30} of the rains were 5 and 21 % greater, respectively. The value of the K factor of 0.0275 $Mg\ ha\ h\ ha^{-1}\ MJ^{-1}\ mm^{-1}$ calculated from data of the experimental year was 57 % greater than the value of 0.0175 $Mg\ ha\ h\ ha^{-1}\ MJ^{-1}\ mm^{-1}$ found by Schick et al. (2014b) in a historical series of data over 20 years for the same soil.

Table 3. Values of SL estimated by the USLE and RUSLE, R factor (EI_{30}), K factor, L factor, S factor, C factor, and P factor in the different treatments (Treat) (average of replications)

Treat	SL	R (EI_{30})	K	L	S	C	P
	$Mg\ ha^{-1}$	$MJ\ mm\ ha^{-1}\ h^{-1}$	$Mg\ ha^{-1}\ h\ ha^{-1}\ MJ^{-1}\ mm^{-1}$	Dimensionless			
USLE							
11 m	111	6,066	0.0275	0.706	0.944	1	1
22 m	149	6,066	0.0275	1.000	0.893	1	1
33 m	166	6,066	0.0275	1.222	0.812	1	1
44 m	185	6,066	0.0275	1.411	0.787	1	1
RUSLE							
11 m	111	6,066	0.0275	0.710	0.934	1	1
22 m	153	6,066	0.0275	1.000	0.916	1	1
33 m	174	6,066	0.0275	1.210	0.863	1	1
44 m	195	6,066	0.0275	1.384	0.844	1	1

The values of the L factor calculated showed a lower numeric variation between the two versions (USLE and RUSLE) of the model, while the values of the S factor ranged more widely in the interval of the treatments (Table 3). For the USLE, the L factor ranged from 0.706 in the slope length of 11 m to 1,411 m in 44 m, whereas for the RUSLE, the same factor ranged from 0.710 to 1.384 in the respective slope lengths. For the S factor in the USLE, the range of values for these slope lengths was 0.944 to 0.787, whereas for the RUSLE, this variation was from 0.934 to 0.844.

The SL estimated by the USLE ranged from 111 mg ha⁻¹ for the slope length of 11 m to 185 mg h⁻¹ for 44 m, whereas for the RUSLE, the variation in SL was from 111 to 195 mg h⁻¹ in the respective treatments (Table 3). The USLE and RUSLE underestimated the SL compared to the observed values (Table 1) for the four treatments, despite the fact that the values of the R and K factors used in calculation of the SL estimated in the research period were higher than the values determined by Schick et al. (2014a,b). For the USLE, the estimate was 13 % lower than the observed data in the average of treatments, whereas for the RUSLE, the estimates were 10 % lower than those observed, with the error of the estimates decreasing with increasing slope length, for both versions.

The lower SL values predicted by the USLE and RUSLE in relation to the observed data occurred due to the fact that this model was developed for temperate climate conditions. There was thus an underestimation of the values of the model input factors, especially the R factor, due to discrepancy between the rainfall pattern in the conditions where the model was developed and the prevailing climate in the research area. Equation 5, proposed for the USLE, was used to calculate the kinetic energy of the rains. This may configure the theoretical basis to explain the underestimation of SL values estimated by the model, in its two versions, in relation to the SL observed. Furthermore, any model for prediction of phenomena is a mere approximation of reality, which, in itself, explains the error between the SL values experimentally observed and the ones estimated. Nevertheless, it can be said that the USLE and RUSLE properly estimated the SL, compared with the observed values, and that the RUSLE estimated the SL better than the USLE.

The changes made in the S factor of the RUSLE, containing different calculations for slopes higher or lower than 9 %, may have partially, but more intensely, influenced the estimate of SL in relation to the USLE, which has a single formula for obtaining the S factor, regardless of the conditions evaluated.

The values of SL observed showed a satisfactory relationship with the L factor for the two versions of the model, the USLE and RUSLE (Figures 4a and 4b). The adjustment coefficient between the variables was significant ($p \leq 0.01$) in the two versions.

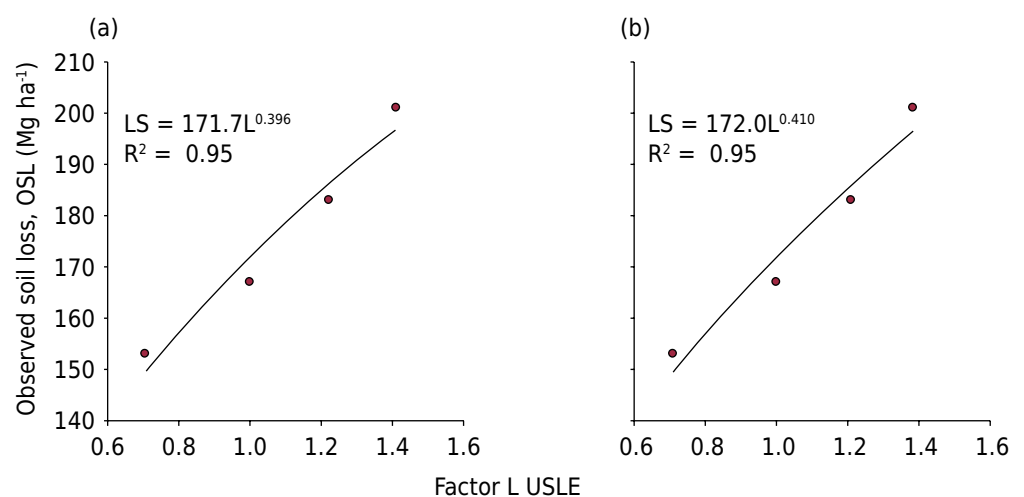


Figure 4. The relation between values of total soil loss (SL) observed in each treatment and the values of the L factor (a) of the USLE and (b) of the RUSLE (average of replicates).

For the USLE, in situations in which the degree of slope of the terrain is equal to or greater than 0.05 m m^{-1} , the relation between SL and the L factor should be: $SL = a L^{0.5}$ (Wischmeier and Smith, 1978). In this equation, L represents the relation between two lengths of slope; a is the intercept of the relation and represents the SL observed in slope length (22.1 m); and b is the exponent that represents the effect of the degree of slope of the terrain. Thus, for the data observed, the value of 0.396 for the exponent b found in the relation (Figure 4a) satisfactorily approached the value proposed by Wischmeier and Smith (1978) for the USLE, which is 0.5.

For the RUSLE, under the conditions of the study, the value of the exponent b in the equation of the factor L, calculated according to equations 2, 3, and 4, would be 0.487. The equation adjusted for the SL observed versus the L factor resulted in a value of 0.410 (Figure 4b). Thus, the value of b, of 0.410, found in the RUSLE version was closer to the calculated value (0.487) for this version than that observed for the USLE version (Figure 4a). The relatively small difference between the estimated and observed values for the USLE and RUSLE (Figures 5a and 5b, respectively) means that for the conditions of the study, the two versions estimated the SL with good approximation to the observed losses, constituting appropriate tools for prediction of SL, especially the RUSLE. Both versions of the model, but mainly the USLE, underestimated the SL. As for the effectiveness of the model, there was little variation between the observed data and the estimated data, especially in the largest slope lengths, as also observed in the study by Tiwari et al. (2000). Comparing the SL estimated by the USLE and RUSLE in plots under natural rain conditions, the authors found that, in general, the efficiency of the model was low for low values of SL, while for high SL, the efficiency was high. The results obtained for the RUSLE agrees with that obtained by Cecílio et al. (2009) in a study in a hydrographic micro basin of Viçosa, Minas Gerais, Brazil, in a *Latosolo Vermelho-Amarelo* (Oxisol); it was observed that the model underestimated the SL. The results also agree with Spaeth et al. (2003), who, in results obtained by using simulated rainfall, showed a strong tendency of the RUSLE to underestimate the SL. Risse et al. (1993) and Nearing (1998) verified that two versions of the model tended to overestimate the SL when they occurred in small quantities and to underestimate when in large quantities. The tendency of the USLE and RUSLE to underestimate SL disagrees with the results obtained by Amorim et al. (2010), who found a tendency of overestimation of SL by the models, regardless of the amount of soil lost.

There were no significant differences in the estimated values of SL using the USLE and RUSLE for the different slope lengths in the study (Figure 6), meaning that both versions of the model turned out to be useful tools for SL prediction under the conditions evaluated.

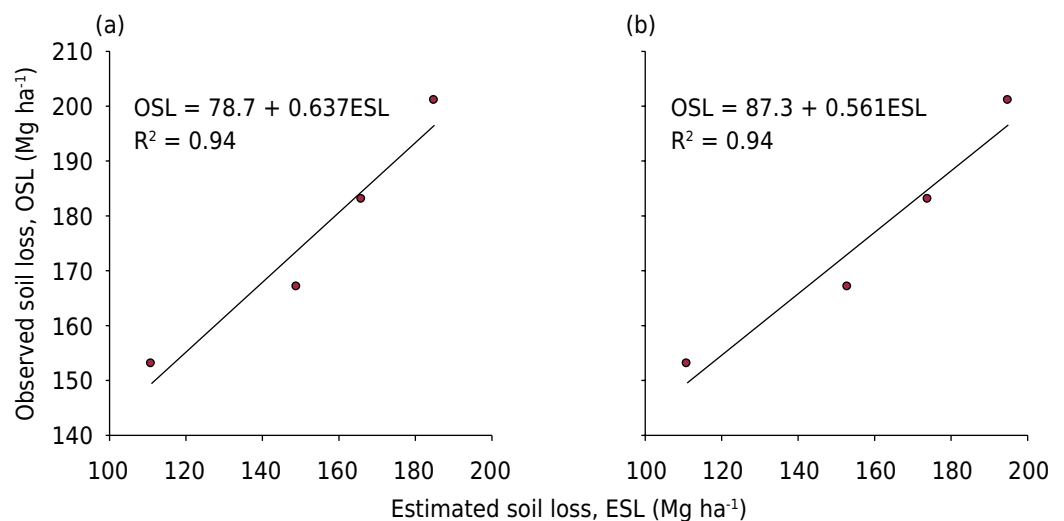


Figure 5. Relation between the values of observed soil loss (OSL) and the values of estimated soil loss (ESL); estimates made (a) by the USLE and (b) by the RUSLE in each treatment (average of replicates).

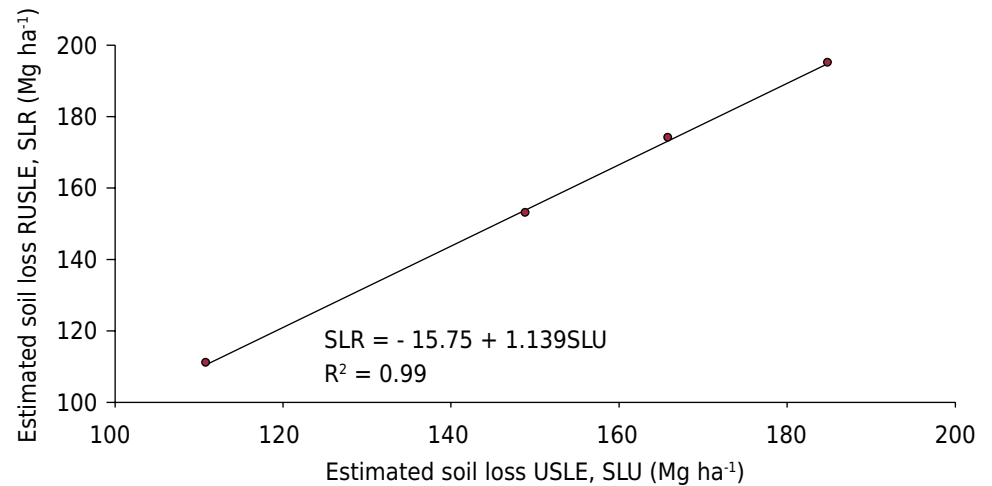


Figure 6. Relation between values of soil loss estimated by the RUSLE (SLR) and estimated by the USLE (SLU) in each treatment (average of replicates).

The use of this model in the USLE and RUSLE versions for SL prediction was only possible because of a database covering more than 20 years for the area under study. It should be noted that this erosion model was developed in temperate environments, to which its parameters were fitted, conditions quite different from the climate and soil conditions found in subtropical and tropical climates. Thus, according to Amorim (2003), it is essential to carry out a performance evaluation of this model when applied to Brazilian conditions before it is extensively used for prediction of SL. In addition, it is recommended that more water erosion studies be carried out under both natural rainfall and simulated rainfall conditions in different regions of the country so as to form a national database that allows use of this model throughout Brazil. It should be noted that problems related to underestimations or overestimations of SL values can be partially mitigated when more research is done so that all the values of the factors influencing erosion become known for different locations.

CONCLUSIONS

In the range between 11 m and 44 m, the soil losses by erosion are related in a positive and linear manner with an increase in slope length.

Water losses are related to rain amount; and soil losses are related to water loss and to the E_{30} .

Soil losses estimated by the USLE and RUSLE model have lower values than those observed experimentally in the field for bare soil at slope lengths between 11 m and 44 m, particularly the values estimated by the USLE.

The values of the L factor calculated for slope lengths of 11 m, 22 m, 33 m, and 44 m for the two versions (the USLE and RUSLE) of the soil loss prediction model show satisfactory results in relation to the soil loss values observed.

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