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Soil Erodibility under Natural Rainfall Conditions as the K Factor of the Universal Soil Loss Equation and Application of the Nomograph for a Subtropical Ultisol

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ABSTRACT: Erodibility represents the intrinsic susceptibility of the soil to the erosion process, represented by the K factor in the Universal Soil Loss Equation (USLE). In Brazil, there are few field experiments determined with a series larger than ten years of data, which are the most reliable for quantifying the K factor. The aim of this study was to determine the K factor of the USLE by the direct method, relating soil losses determined in the field under standard conditions to erosivity of rains, and by the analytic method, applying the Wischmeier nomograph. The data on soil loss by water erosion were obtained in a field experiment under natural rainfall conditions from 1976 to 1989 in an Ultisol at the Agronomic Experimental Station in Eldorado do Sul, RS, Brazil. The value of the K factor by the direct method was 0.0338 Mg ha h ha^{-1} MJ^{-1} mm^{-1}, which is high, showing considerable susceptibility of the soil to erosion. From the analytical method, the K factor obtained was 0.0325 Mg ha h ha^{-1} MJ^{-1} mm^{-1}, a value very close to that determined experimentally. Thus, the Wischmeier nomograph proved to be valid for determination of the K factor of the Ultisol under study. This method proved to be valid for this type of soil. These results can be used for calibration models based on the USLE.

Keywords: water erosion, soil loss, soil properties, erosion modeling, surface runoff.

INTRODUCTION

Erosion is a process of wearing away the surface of rocks and soils. When it occurs as geological or natural erosion, it is an important component of the natural evolution of the physical ecosystem and the development of landscapes. However, when it occurs as anthropic or accelerated erosion, it can affect soil quality and water resources; it is, therefore, an undesirable form of erosion. Soil erosion is considered one of the most damaging environmental problems, and irreparable damages can occur in nature and even in cities, and it can become a socioeconomic problem (Wang et al., 2013). In addition, soil erosion restrains sustainable soil use and development of rural areas (Zheng et al., 2004; Jing et al., 2005).

The main measure for conservation and management of natural resources is prevention of water erosion (Sadeghi et al., 2007). Prediction of susceptibility to soil erosion and verification of the main sources of erosion in an area constitute the beginning of choosing suitable strategies for erosion control (Auerswald et al., 2014). Soil erosion modeling is an effective tool to evaluate the efficiency of active strategies to adopt with the aim of effective agricultural management. According to Auerswald et al. (2014), the model most often used for soil erosion predictions worldwide is the Universal Soil Loss Equation - USLE (Wischmeier and Smith, 1978).

Among the USLE factors required for predict soil losses, the erodibility (represented by the K factor) indicates the inherent condition of the soil, hence, the susceptibility to detachment and transport by erosion processes (Wischmeier and Smith, 1978; Renard et al., 1997). It is essential for predicting soil loss and evaluating its environmental effects (Wang et al., 2016).

The K factor is determined by annual soil loss and annual rainfall erosivity. According to the USLE model, the unit plot should be 22.1 m in length with a slope of 9 %, and it should remain uncovered, with conventional tillage along the slope (Wischmeier and Smith, 1978). A long-term field experiment must be carried out to more precisely determine the K factor, mainly due to annual variation in potential rainfall erosivity. This is not only a time-consuming procedure, but is also very expensive. Some efforts have been made in an attempt to find a quicker and less expensive way to obtain the K factor. Wischmeier and Mannering (1969) studied erodibility from 24 basic soil properties and their interactions. They showed that there are four main properties considered to affect soil erodibility. They include soil particle composition, soil structure, percentage of organic matter, and soil permeability, which lead to greater or lesser susceptibility to erosion (Wischmeier and Mannering, 1969; Wischmeier et al., 1971; Wischmeier and Smith, 1978). Wischmeier et al. (1971) developed the first analytic method to estimate soil erodibility, which is a graphical representation (nomograph) based on an indirect combination of physical properties and percentage of organic matter. Erodibility can also be expressed in mathematical terms (Wischmeier et al., 1971; Wischmeier and Smith, 1978) for calculation of the K factor, instead of reading the nomograph.

The use of the nomograph is adequate for surface soils, less aggregated soils, and medium-textured soils (more sandy than clayey) of the Midwest of the Unites States (Römkens et al., 1997). These authors explain that several researchers tried to apply the nomogram in other regions and other classes of soils, but this application was not successful. There was good correlation between the values measured directly in the field and the values estimated by the nomogram when applied to soils with properties and parameters similar to the Midwest region. It became difficult and the correlations were poorer when exceeding the nomograph limits (Morgan, 2005). This problem occurred for soils with high organic matter content (more than 4 %), swelling clays, and soils in which aggregate stability is more influential than primary particle size (Renard et al., 1997; Morgan, 2005). According to Singh and Khera (2009), the nomograph has been used worldwide to estimate soil erodibility using easily assessed analytical parameters. However, determinations of erodibility using the nomograph have been satisfactory only under the conditions in which it was developed and inadequate in other regions with different soils. Thus, discrepant values for other types of soils are observed (Vanelslande et al., 1987).

Using the nomograph in tropical countries is not recommended because it usually overestimates K values (Lo et al., 1985). According to these same authors, a possible explanation for this behavior stems from the fact that it does not consider the effects of iron and aluminum oxides, the main particle-aggregating agents of soils in tropical climate regions. The advantages of the use of analytical methods are speed and lower cost in determination of the erodibility of soils in comparison to direct methods because the method initially proposed for quantification of this index (K factor) not only is very costly and slow, but also requires a long time to obtain definitive data on the soil (Silva et al., 2003). Analytical methods may also allow estimation of the K value through parameters obtained by laboratory analyses that can be easily performed.

Such information, as for K values, is lacking in Brazil, since there are many Brazilian soil classes and, within a class, there are differences in K factor value. Furthermore, there are few field experiments determined with a series longer than ten years of data; such series are most reliable for quantifying the K factor, as recommended by the USLE methodology.

The objective of this study was to determinate the USLE K factor (soil erodibility) by direct measurement using a historic series of 13 years of experimentation on an Ultisol. Secondly, an attempt was made to validate the USLE K factor by mathematical equation based on the nomograph with analytical parameters for this soil.

MATERIALS AND METHODS

Description of the study area

A field experiment to evaluate soil losses by water erosion was conducted under natural rainfall conditions at the experimental station of the Federal University of Rio Grande do Sul (*Universidade Federal do Rio Grande do Sul* - Ufrgs) in Eldorado do Sul, RS, Brazil (30° 05’ South, 51° 39’ West, and 42 m a.s.l.). The slope was 12 % (Eltz, 1977). The local climate is humid subtropical (Köppen Cfa), with mean annual temperature of 18.8 °C and mean annual rainfall of 1,455 mm (Bergamaschi et al., 2013). The soil is classified as Ultisol (WRB, 2014), which corresponds to an *Argissolo Vermelho-Amarelo distrófico típico*, according to Brazilian Soil Classification System (Santos et al., 2013), with low natural fertility, low organic matter content, and sandy clay loam texture.

Experimental plot

Soil loss data were evaluated over 13 years of field experimentation from the winter of 1976 to the summer of 1989. The present study was conducted in a USLE unit plot, with one replication (one plot). The unit plot was set up with dimensions of 22.0 × 3.5 m (77 m^2). The unit plot was marked off by galvanized steel sheets (height 0.20 m) driven into the soil to a depth of 0.10 m. At the lower end of the plot, there were runoff collection systems consisting of gutters, PVC pipes, and two collection tanks connected through GEIB divisors for collection of the water volume.

Sampling soil loss

After each erosive rainfall event or group of erosive rainfalls, the surface runoff was collected by the set of tanks. Sampling was conducted whenever possible after each erosive rainfall. However, on many occasions, sampling was carried out by accumulating soil loss caused by more than one erosive rainfall or non-erosive rainfall. The sediments inside the tanks were removed, sampled, and taken to the erosion laboratory for quantification.

Rainfall erosivity index (EI_{30})

Determination of rain erosivity was made for each individual erosive rain using the EI_{30} index (Wischmeier, 1959). The data obtained from pluviographs were analyzed by the Chuveros program, developed by Professor Elemar Antonino Cassol of the Soil Department of the Ufrgs, obtaining the EI_{30} index in the International System of Units for each erosive rainfall (Foster et al., 1981).

For determination of the kinetic energy of each segment of the individual erosive rains, the program makes calculations according to equation 1, which is the standard for determining the *R* factor of the USLE (Wischmeier and Smith, 1978):

$$e_c = 0.119 + 0.0873 \log i \qquad \text{Eq. 1}$$

in which e_c is the kinetic energy for each rain segment in MJ ha^{-1} mm^{-1} and *i* is the rainfall intensity of each segment in mm h^{-1}. The total kinetic energy in each rain segment (Es, in MJ ha^{-1}) is obtained by equation 2:

$$Es = e_c\, p \qquad \text{Eq. 2}$$

in which e_c is the kinetic energy (MJ ha^{-1} mm^{-1}) for each rain segment; and p is the rainfall (mm) in the segment.

Total kinetic energy of the rain (Et, in MJ ha^{-1}) is obtained by the sum total of kinetic energy of each rain segment (Es), according to equation 3:

$$Et = \Sigma\, Es \qquad \text{Eq. 3}$$

in which Es is the kinetic energy of each rain segment (MJ ha^{-1}).

With the product of total kinetic energy of the rain (Et, in MJ ha^{-1}) through greatest intensity for 30 minutes (in mm h^{-1}), the erositivity index (EI_{30}; in MJ mm ha^{-1}) is obtained, of each rain, according to equation 4:

$$EI_{30} = Et\, I_{30} \qquad \text{Eq. 4}$$

in which Et is the total kinetic energy of the rain; and I_{30} is the greatest maximum intensity in 30 min (mm h^{-1}).

Estimate K factor (soil erodibility)

Measurements of soil loss in the unit plot

The soil erodibility factor (K) was determined based on annual soil loss (Mg ha^{-1}) from the USLE unit plot (22.0 m long with a uniform 9 % slope, continuously maintained in a clean-tilled fallow condition with upslope and downslope tillage) by means of the annual rainfall erosivity index (MJ mm ha^{-1} h^{-1} yr^{-1}) for each crop year (Wischmeier and Smith, 1978). The standard procedure for the K factor used 13 years of soil loss evaluation in the field under natural rainfall and rainfall erosivity by the EI_{30} index in the same period; soil loss was evaluated in the field under the bare soil treatment in a plot that was 22.0 m long with a 12 % slope. In order to adapt the standard unit conditions for determination of the K factor to this study, an adjustment of soil losses to 9 % slope was made, according to equation 5 (Wischmeier and Smith, 1978):

$$S = 4.56 \text{ sen } \theta + 65.41 (\text{sen } \theta)^2 + 0.065 \qquad \text{Eq. 5}$$

in which *S* is the slope factor and θ is the slope angle (degree).

The correction factor for adjustment of soil losses to 9 % slope was 1.536. The original soil losses of the field were divided by this factor to be able to adapt to the 9 % level. The K factor was calculated using the following simplified equation 6, proposed by Wischmeier and Smith (1978):

$$K = A/RS \qquad \text{Eq. 6}$$

in which K represents the soil erodibility factor (Mg ha h ha^{-1} MJ^{-1} mm^{-1}); A is the annual soil loss (Mg ha^{-1} yr^{-1}) determined in an experimental unit (standard) for 12 % slope; *R* is the rainfall erosivity factor (MJ mm ha^{-1} h^{-1}); and *S* is the slope steepness factor to 12 % (1.536). The final *K* factor for the soil is the mean of the values obtained for each one of the 13 years of experimental evaluation.

Using the line slope of simple regression analysis between soil losses and the erosivities referred to also provided the K factor value, according to the method proposed by Wischmeier and Mannering (1969), passing the line through the origin. The model used was Y = bX, in which Y corresponds to soil losses, b is the K factor, and X is the rainfall erosivity. The statistical procedures used to analyze the results were the mean, standard deviation, coefficient of variation, and significance testing.

To evaluate the influence of the period for determination of the K factor, a mean of the years evaluated was calculated. First, we used one year, then a mean of the first and second year, then a mean of the first, second, and third year, and so on progressively until completing the mean of 13 years.

Estimating the soil erodibility nomograph (equation)

For the purpose of validating the nomograph method by Wischmeier et al. (1971) for an Ultisol, the K factor was also determined by the indirect method and compared with the result of the measured method, which is the standard for this determination of the USLE K factor.

Indirect determination of the *K* factor by the nomograph method from Wischmeier et al. (1971) was made through knowledge of the following soil parameters: percent of silt + very fine sand fraction (0.002-0.1 mm), percent of clay fraction (<0.002 mm), percent of sand fraction (0.1-2.0 mm), organic matter content (%), a code for soil structure (1-4), and a code for soil permeability (1-6).

Data from particle size analysis were obtained from the dissertation of Souza (1976) because the author conducted his study next to our experimental area, which was used for direct evaluation of the K factor in the present paper (Table 1). The organic matter content was obtained from the dissertation of Saraiva (1978), who conducted an experiment in the same area as the present study (Table 1).

Wischmeier et al. (1971) refers to structure and permeability classes according to codes. These structure and permeability variables were obtained based on general description of the soil profile and morphological description of the soil surface in the first 0.25 m (Saraiva, 1978). Structure was classified as blocky, laminar, or massive, and the code determined was 4. Permeability was classified as low to moderate, and the code determined was 4 (Souza, 1976). Equation 7 that follows can represent the nomogram under one condition - the sum of silt plus very fine sand should be less than 70 % (Wischmeier et al., 1971; Wischmeier and Smith, 1978):

Table 1. Particle size analysis of soil with different classes of sand, silt, and clay, organic matter content, and texture (adapted from Souza, 1976)

Layer	Gravel	Particle size distribution(1)								OM(2)
		VCS	CS	MS	FS	VFS	TS	S	C	
m	%									
0.00-0.25	3.3	6.5	10.6	12.6	24.3	7.3	61.3	21.6	17.1	1.51

(1) Hydrometer method (Bouyoucos, 1951). (2) Organic matter obtained from Saraiva (1978). Gravel: (>2.0 mm); VCS: very coarse sand (1.0-2.0 mm); CS: coarse sand (0.5-1.0 mm); MS: medium sand (0.2-0.5 mm); FS: fine sand (0.1-0.2 mm); VFS: very fine sand (0.05-0.1 mm); TS: total sand (0.05-2.0 mm); S: silt (0.002-0.05 mm); C: clay (<0.002 mm).

$$K = [2.1\ M^{1.14}\ (10^{-4})\ (12\text{-}a) + 3.25\ (b\text{-}2) + 2.5\ (c\text{-}3)]/100 \qquad \text{Eq. 7}$$

in which *K* is the USLE soil erodibility factor; a, b, and c are the percentage of organic matter, the structure code, and the permeability code, respectively; *M* is the product of the percent of silt + very fine sand and the percent of all soil fractions other than clay. The K factor values obtained by the equation or nomograph constructed with the parameters must be multiplied by a factor of 0.1313 to be able to express the results in the International System of Units (Wischmeier and Smith, 1978).

RESULTS AND DISCUSSION

K factor of USLE as soil erodibility

The mean annual K factor is the ratio between soil losses and the rain erosivity index, determined on an annual basis. The annual K factor varied widely in the period under study (Table 2). This is due to variation in soil losses throughout the period of evaluation, as well as to variation in erosivity of the rains. The annual mean of the period studied is considered to be the value of the K factor, which represents the erodibility of the soil in the USLE determined for the Ultisol characterized in the experimental area. The value determined for the K factor was 0.0338 Mg ha h ha^{-1} MJ^{-1} mm^{-1}. According to the erodibility classification of Foster et al. (1981), this is considered high; that is, it is a soil highly susceptible to erosion.

Among the annual values observed, the lowest K factor found was 0.0106 Mg ha h ha^{-1} MJ^{-1} mm^{-1} in the 1988/89 crop year, and the highest value was 0.0681 Mg ha h ha^{-1} MJ^{-1} mm^{-1} in 1984/1985, a difference of approximately 6 times between these two values. Although erosivity was 35 % greater in 1984/85, it nevertheless caused approximately 90 % greater soil loss in that year. This can probably be explained by better distribution of rains in 1988/89, that is, a greater space between them and, consequently, lower soil moisture content preceding most of the rains (Bertol et al., 2002). The rains in 1988/89, with the lowest value of erosivity, produced the lowest soil losses by water erosion possibly because they fell on soil with lower moisture content.

Table 2. Soil losses observed and adjusted to 9 % slope ("*S*" factor = 1.536) in the bare soil treatment (standard plot of the USLE) for determination of the K factor in the 13 years of carrying out the experiment, from 1976/77 to 1987/88 in Eldorado do Sul, RS, Brazil

Year	Soil losses		EI_{30}	K factor
	Observed	Adjusted(1)		
	Mg ha^{-1} yr^{-1}		MJ mm ha^{-1} h^{-1}	Mg ha h ha^{-1} MJ^{-1} mm^{-1}
1976/1977	288.87	187.97	10,123.9	0.0186
1977/1978	81.39	52.96	3,730.0	0.0142
1978/1979	215.49	140.22	3,717.1	0.0377
1979/1980	377.87	245.88	9,788.8	0.0251
1980/1981	301.43	196.14	4,551.3	0.0431
1981/1982	183.36	119.31	4,050.4	0.0295
1982/1983	445.51	289.89	6,355.9	0.0456
1983/1984	521.78	339.52	7,082.8	0.0479
1984/1985	502.25	326.82	4,802.0	0.0681
1985/1986	189.86	123.54	3,380.9	0.0365
1986/1987	283.58	184.53	6,834.0	0.0270
1987/1988	293.13	190.74	5,339.8	0.0357
1988/1989	50.51	32.87	3,138.5	0.0105
Mean	287.31	186.95	5,604.5	0.0338
SD	146.8	95.5	2,319.3	0.0156
CV (%)	51.1	51.1	41.4	46.1

(1) Soil losses adjusted to 9 % slope.

Observing the values of soil losses and erosivity, it can be seen that high erosivities did not cause the greatest soil losses in all years, just as the years with lowest erosivities did not always cause the lowest soil losses. Nevertheless, it was more common for rains of low erosivity to produce considerable soil losses. This was also observed in a study performed by Silva et al. (2009) in a *Cambissolo Háplico* (Inceptisol), indicating that perhaps the preceding soil moisture was high at some time, favoring soil loss from rains with low erosivity and from non-erosive rains, due to their small depth, just as the Ultisol, causing rapid saturation, favored greater surface runoff and greater transport of particles. However, in this study we did not measure the daily soil moisture.

The data of simple linear regression between soil losses and respective erosivities are shown in figure 1 considering two situations: (a) includes all the collections of soil losses while the experiment was being carried out, from accumulated erosive and non-erosive rains (Figure 1a); and (b) includes only the mean annual soil losses and the respective yearly mean erosivities of the 13 years of the experiment (Figure 1b). There was large data dispersion, which was indicated by the relatively low value of the coefficients of determination of 0.5101 for figure 1a with all the collections of erosive and non-erosive rains together, and of 0.2061 for figure 1b with the mean annual soil losses and erosivities. The erodibility determined by simple linear regression was 0.0290 Mg ha h ha^{-1} MJ^{-1} mm^{-1} for accumulated rains. Conceptually, the mean erodibility observed indicates that each unit of erosivity brought about mean annual soil loss of 0.0290 Mg ha^{-1} (Schick et al., 2014). This value was approximately 14 % less than the value found in the standard plot (factor K = 0.0338 Mg ha h ha^{-1} MJ^{-1} mm^{-1}). This result is in disagreement with Eduardo (2012), who worked with the same class of soil and found an increase of 15.09 % in relation to the standard method, and Bertol et al. (2007), who worked with a Hapludox in Lages, SC, and found a 9 % higher value using regression. This difference may have occurred because these authors determined the K factor from individual rains. Schick et al. (2014) found an erodibility value of 0.0172 Mg ha h ha^{-1} MJ^{-1} mm^{-1} by regression, a value similar to that obtained by the standard method for calculation of this factor (0.0175 Mg ha h ha^{-1} MJ^{-1} mm^{-1}).

The dispersion data in regard to annual soil losses and erosivities of the 13 years of evaluation are shown in figure 1b. It can be observed that the relation between soil losses and erosivities had a lower coefficient of determination (R^2 = 0.2061) and a

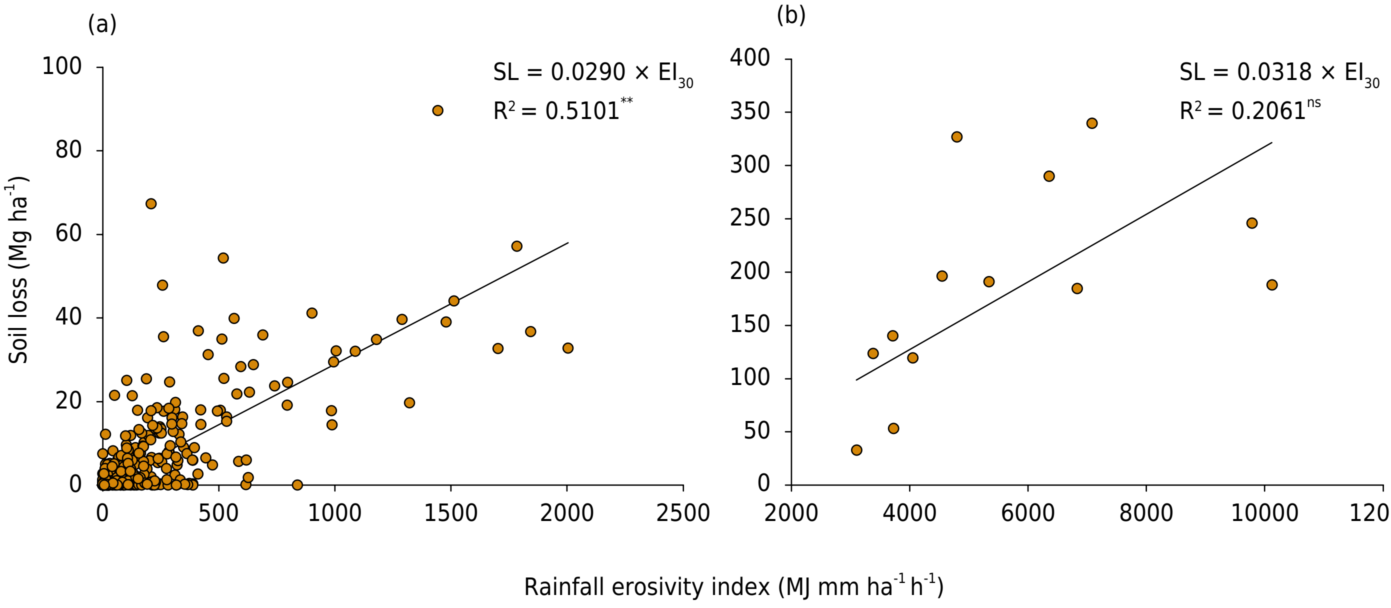

Figure 1. Relation of the erosivity index (EI_{30}) to the respective soil loss (a) with all the collections of soil losses with accumulated erosive and non-erosive rains and (b) with the mean annual soil losses and mean annual erosivities over the 13 years of carrying out the experiment, in Eldorado do Sul, RS, Brazil. ^{ns}: non-significant; **: significant at the level of 1 %.

higher K factor value, at 0.0318 ha h ha^{-1} MJ^{-1} mm^{-1}. For this dispersion, there was a reduction of 6 % in relation to that determined by the ratio of annual soil losses and annual erosivity. Therefore, as the R^2 was low, and the erodibility values found were also low, it is recommended that the K factor of 0.0338 ha h ha^{-1} MJ^{-1} mm^{-1} determined under standard conditions be used for the Ultisol. The low values of coefficients of determination indicate that the adjusted model is influenced by other variables in soil losses and not only erosivity. These variables may be the moisture preceding the erosive rains because many data used in the regression were from collections of soil losses from more than one erosive and non-erosive rain. Thus, in some cases, soil losses were collected from four rains that were not erosive but that caused soil losses, possibly through accumulating near the collection gutter, or through the effects of soil mobilization at times of tillage.

Some authors determined the K factor for Ultisol using the same method of the relation between soil losses and the respective erosivities. Marques et al. (1997), working with natural rain over three years of data, obtained a K factor of 0.033 Mg ha h ha^{-1} MJ^{-1} mm^{-1} for the region of Sete Lagoas, MG, a value near that found in this study. Campos Filho et al. (1992), working over four years in Glória de Goitá, PE, found a K factor value of 0.014 Mg ha h ha^{-1} MJ^{-1} mm^{-1}. Eduardo (2012), working with five years of data in Seropédica, RJ, found a K factor value of 0.0090 Mg ha h ha^{-1} MJ^{-1} mm^{-1}. These values of the K factor are lower than the value found in this study. These differences may have occurred mainly due to the short time of determination of the factor and from the textural differences of each soil. Erodibility is highly variable due to the wide variety of soils with different properties, making it risky to estimate a value based solely on soil classification (El-Swaify and Dangler, 1982; Marques et al., 1997). Thus, spatial variability of physical and chemical properties may occur, due to the result of the combination of climatological, geological, and topographic factors. These factors may grant a certain physical and/or chemical peculiarity and, therefore, lead to a specific K factor value (Silva et al., 2003; Bertoni and Lombardi Neto, 2012).

Variation of the K factor by time of evaluation

Figure 2 represents the values of the mean K factor accumulated over time according to the number of years of evaluation. The K factor value increased until around 10 years of evaluation and then stabilized. Therefore, a K factor determined over a period of 10 years or more is much more reliable that one determined over one to nine years, for instance. Results confirm that the factors of the USLE should be determined over long periods. Schick et al. (2014), evaluating the effect of the K factor accumulated over 20 years of experimentation in an Inceptisol in Lages, SC, observed the same shape of the curve shown in figure 2, with a greater increase in the erodibility value in the beginning years of evaluation and lower increase in the final years. Campos Filho et al. (1992) found this effect in obtaining the K factor by the direct method, in which the erodibility increased as the years of cropping passed, and this difference between each value became less and less. These same authors explain that the possible reasons for this difference are in the reduction of organic matter and the decrease in stability of the aggregates, which occurs over time in cropped areas.

Figure 2 shows that there was a decline in the erodibility values after 9-10 years of data. This could be related to the loss of the entire surface horizon of the Ultisol over the 13 years of soil losses in this treatment with bare soil. However, Saraiva (1978), through surveys and classification of the soil in this area determined that the soil A horizon had a depth of around 0.65 m. Considering that at a density of 1.4 Mg m^{-3}, the total soil losses over 13 years of the experiment of 3,735.03 Mg ha^{-1} would represent a uniform layer of approximately 0.27 m, characterizing that soil during the experiment period did not change the features. This excludes the possibility that decline in the K factor value when including the 10, 11, 12, and 13-year data from assessments could have been caused by an increase in clay due to soil conditions involving the B textural horizon.

Soil erodibility by the equation of Wischmeier et al. (1971)

Using equation 4, the K factor was determined by the analytical method (nomograph), based on the variables that affect soil erodibility (Wischmeier et al., 1971). Table 3 presents the data used in determination of the K factor by the analytical method. The value found was 0.0325 Mg ha h ha^{-1} MJ^{-1} mm^{-1}. This value was 4.0 % less than that determined by the ratio of the soil losses and the rain erosivity, which was 0.0338 Mg ha h ha^{-1} MJ^{-1} mm^{-1}. This shows that it is possible to accurately estimate the USLE K factor through use of the nomograph for the Ultisol like the one used in this study in the region of Eldorado do Sul, Brazil. As was also observed by the direct method, this soil has high susceptibility to erosion, due to the high value of the K factor. This is associated with the high content of silt + very fine sand and with the low clay content of this soil, generating a high value of M (2,396), together with low to moderate permeability (Souza, 1976) and with low organic matter content in the soil, which is a cementing agent. Wischmeier et al. (1971) affirm that erodibility normally tends to increase with increased silt content and reduce with an increase in organic matter and the clay fraction of the soil.

Various authors have determined the K factor by the nomograph method for Ultisol. Campos Filho et al. (1992), working in Glória de Goitá, Pernambuco, found a value of 0.013 Mg ha h ha^{-1} MJ^{-1} mm^{-1}. Eduardo (2012), working in Seropédica, Rio de Janeiro, found a value of 0.0281 Mg ha h ha^{-1} MJ^{-1} mm^{-1}. Oliveira and Bahia (1984), studying the erodibility of soils by the nomograph, found a value of 0.016 Mg ha h ha^{-1} MJ^{-1} mm^{-1} for the surface horizon of the Ultisol. Denardin (1990) reports that all adjusted models for American and

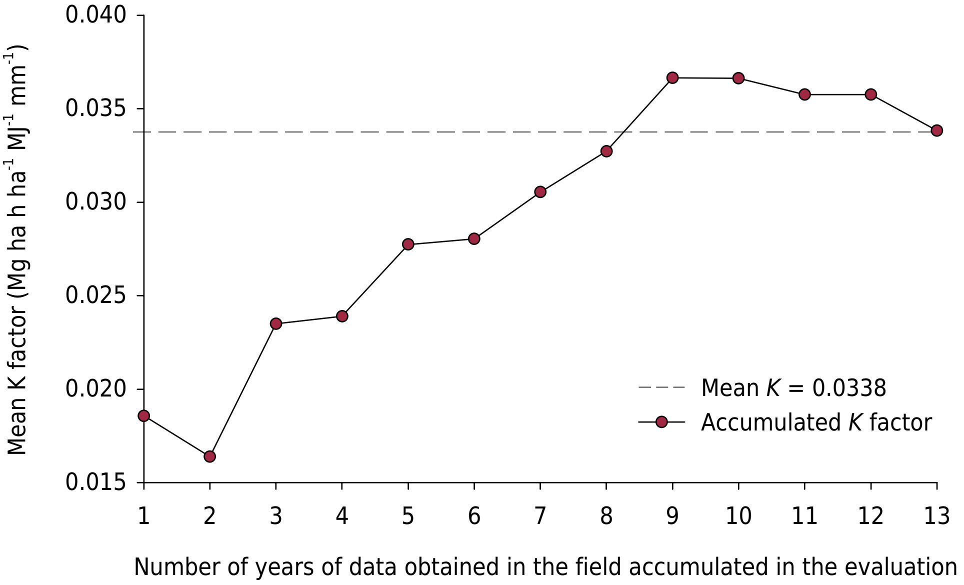

Figure 2. Variation of the K factor of the USLE according to time of evaluation, in Eldorado do Sul, RS, Brazil.

Table 3. Particle size, organic matter, structure, and permeability data used in determination of the K factor by the equation coming from the nomograph of Wischmeier et al. (1971)

Property	Class		Value/Code	K factor
				Mg ha h ha^{-1} MJ^{-1} mm^{-1}
(Silt + VCS) × (100 - % clay)$^{(1)}$	M		2,396	0.0325
Organic Matter (%)$^{(2)}$	a		1.51	
Structure$^{(3)}$	b	Blocks, laminar	4	
Permeability$^{(4)}$	c	Low to moderate	4	

(1) Hydrometer method (Bouyoucos, 1951). (2) Walkley-Black method (Walkley & Black, 1934). (3) Morphological features in soil profile (Mello et al., 1966). (4) Concentric rings infiltrometer method (Bernardo et al., 2005). M: product of the percent of silt + very fine sand and the percent of all soil fractions other than clay; a: percentage of organic matter; b: structure code; c: permeability code.

Brazilian soils with values of the M variable less than 3,000 show low correlation with erodibility. Thus, based on data obtained from this study, the M value could be modified to 2.396 with accuracy of the erodibility determination.

CONCLUSIONS

The field-determined USLE K factor is 0.0338 Mg ha h ha^{-1} MJ^{-1} mm^{-1} for the Ultisol, characterizing a soil highly susceptible to water erosion. The simple linear regression analysis between soil losses determined in the field in all the collections and the respective rain erosivity did not give a good estimate of the USLE K factor. This was also true for the relation between mean annual soil loss and the respective mean annual erosivity. The results also show the K factor determination must be through at least 10 years of experimentation to obtain a reliable value, because a short evaluation period underestimates the K factor by the direct method.

The analytically-determined K factor with use of the Wischmeier nomograph was 0.0325 Mg ha h ha^{-1} MJ^{-1} mm^{-1}. This method proved to be valid for the Ultisol.

The K factor results found in this paper can be used for calibration of other physical and conceptual models based on the USLE.

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