Revista Brasileira de Ciência do Solo

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

Water Erosion in Oxisols under Coffee Cultivation

Henrique Mendes Júnior(1), André Silva Tavares(1), Walbert Júnior Reis dos Santos(2), Marx Leandro Naves Silva(3), Breno Régis Santos(4) and Ronaldo Luiz Mincato(4)*

(1) Universidade Federal de Alfenas, Instituto de Ciências da Natureza, Programa de Pós-Graduação em Ciências Ambientais, Alfenas, Minas Gerais, Brasil.
(2) Instituto Federal de Educação, Ciência e Tecnologia do Sul de Minas Gerais, *Campus* de Muzambinho, Muzambinho, Minas Gerais, Brasil.
(3) Universidade Federal de Lavras, Departamento de Ciência do Solo, Lavras, Minas Gerais, Brasil.
(4) Universidade Federal de Alfenas, Instituto de Ciências da Natureza, Alfenas, Minas Gerais, Brasil.

ABSTRACT: Water erosion is one of the main environmental impacts of land use. When soil and water losses occur, nutrients essential for the growth and maintenance of plants are removed, with harmful outcomes on the sustainability of agriculture and the environment. In addition, they lead to other deleterious effects, such as sedimentation and eutrophication of water bodies. Estimation of soil losses due to water erosion in sub-basins is essential for prediction of soil degradation, especially in areas of semi-intensive cultivation, such as coffee fields. Thus, the aim of this study was to estimate soil losses in relation to the limit of soil loss tolerance in Oxisols (*Latossolos Vermelhos Distróficos*) under coffee cultivation. This study was conducted from March 2015 to January 2017 in the Córrego da Laje Hydrographic Sub-basin in the municipality of Alfenas in the southern region of Minas Gerais, southeastern Brazil. Soil losses due to water erosion were estimated from the revised universal soil loss equation and compared to soil loss tolerance. Morphological, physical, and chemical properties of the soil were used, as well as geoprocessing techniques, remote-sensing images, and data from the literature. The results show potential soil losses from 0.01 to 18.77 Mg ha^{-1} yr^{-1}, with an average of 1.52 Mg ha^{-1} yr^{-1}. The soil loss tolerance ranged from 5.19 to 5.90 Mg ha^{-1} yr^{-1}, with 7.35 % of the area having larger losses. Areas with steeper slopes and no sustainable practices have soil losses above the tolerance level and are thus a priority for adoption of measures to mitigate erosive effects. The revised universal soil loss equation enabled water erosion modeling and identification of areas with the highest rates of potential soil loss in watersheds.

Keywords: soil loss, RUSLE, soil loss tolerance.

*** Corresponding author:**
E-mail: ronaldo.mincato@unifal-mg.edu.br

Received: April 4, 2017
Approved: January 11, 2018

How to cite: Mendes Júnior H, Tavares AS, Santos WJR, Silva MLN, Santos BR, Mincato RL. Water erosion in Oxisols under coffee cultivation. Rev Bras Cienc Solo. 2018;42:e0170093.
https://doi.org/10.1590/18069657rbcs20170093

INTRODUCTION

Water erosion is one of the major processes of soil degradation. It causes losses of soil, water, carbon, and nutrients, which are essential for agricultural and ecological sustainability (Panagos et al., 2015a). This problem has been increased the losses of arable land at rates higher than those of soil formation (Pimentel et al., 1995; Cândido et al., 2014), increasing the risks to food security and the sustainability of terrestrial ecosystems (Pimentel et al., 1995, 2006).

Soil erosion losses in the world are extremely variable. Sites with conservation management practices and sustainable soil use, such as Lake Pelham and Lake Moomaw, located in two environmental reserves in the state of Virginia, USA, show low soil losses, with averages of 2.15 and 2.72 Mg ha^{-1} yr^{-1}, respectively (Clark et al., 2015). However, land use sites with no conservation practices exhibit higher rates, such as in some sites in Africa, with losses of 35 Mg ha^{-1} yr^{-1} for the White Volta Basin in Ghana and Burkina Faso, and 75 Mg ha^{-1} yr^{-1} for the Nile River Basin (Tamene and Le, 2015). In the European Union, average soil losses of 2.46 Mg ha^{-1} yr^{-1} were recorded in agricultural, forest, and semi-natural areas, which illustrates the efficiency of soil conservation management (Panagos et al., 2015b). In South America, average soil losses range from 30 to 40 Mg ha^{-1} yr^{-1}, considering areas with conservation management and others with conventional management (Pimentel et al., 1995). In Brazil, soil losses due to erosion of land planted to annual crops are estimated at 616.5 million Mg yr^{-1}, with costs of US$ 1.3 billion per year (Dechen et al., 2015).

Rain is the natural erosive agent of topographic modeling in tropical regions (Cândido et al., 2014). Rain-related erosion is influenced by soil and topography characteristics, as well as by soil use and management. Thus, studies on soil losses due to water erosion are essential to define suitable conservation practices for crops, to minimize erosion processes, and to allow sustainable growth in crop yield (Oliveira et al., 2015).

To estimate soil losses, empirical equations such as the universal soil loss equation (USLE) (Wischmeier and Smith, 1978) and the revised universal soil loss equation (RUSLE) (Renard et al., 1997) are used, as are physical and conceptual models such as the water erosion prediction project (WEPP) (Nearing et al., 1989), the European soil erosion model (Eurosem) (Morgan et al., 1998), and the erosion potential method (EPM) (Gavrilovic, 1988), among others. The quantification of water erosion by the USLE is more applicable than the physical and conceptual models. However, RUSLE, partially overcomes climatic and geographic restrictions. It was originally proposed for the climatic conditions of the Unites States and, together with the use of geographic information systems (GIS), remote sensing, and modern geostatistical methods for factor calculation, it can be applied to different regions, under different climatic conditions, and in environments more complex than experimental plots, such as watersheds (Morgan and Nearing, 2011; Karydas et al., 2014). In Brazil, USLE and RUSLE are the tools most used to evaluate water erosion (Avanzi et al., 2013).

One way to evaluate the impacts of soil losses by water erosion is to compare the results estimated by models such as RUSLE with the limits of soil loss tolerance (T). Soil loss tolerance reflects the maximum level of erosion that allows sustainable agricultural production (Wischmeier and Smith, 1978). It is a difficult parameter to obtain due to the difficulties of calculating soil formation rates. For this reason, soil properties, such as organic matter, soil water permeability, and the textural relationship between the B and A horizons, which indirectly reflect soil formation rates, are used to define T. Conceptually, every soil has a T limit, which is related to its formation rate. Thus, T calculations are complementary to the estimates of water erosion and allow a more accurate evaluation of the state of soil degradation (Bertol and Almeida, 2000). In Brazil, the method of Bertol and Almeida (2000) is the most recent and the most used for calculation of T because it considers a greater variety of soil porperties and the ease of obtaining them (Cândido et al., 2014; Olivetti et al., 2015). In the case of Oxisols (*Latossolos*), the method that considers organic matter content and permeability of the soil to water is the most appropriate. However, according to the Food and Agriculture Organization of the United Nations and the Intergovernmental Technical Panel on Soils (FAO and ITPS, 2015), soil loss tolerance levels are useful for setting short-term goals. However, the long-term sustainability of agricultural land requires reduction of soil erosion rates to close to zero.

In the south of the state of Minas Gerais, Brazil, there are coffee-growing areas of national economic importance. This production is characterized by extensive soil use but with few assessments of soil loss due to water erosion, according to Carvalho et al. (2007), who evaluated water erosion in Oxisols (*Latossolos Vermelhos*) under different management systems in a standard 12 × 24 m plot. The authors concluded that soil losses were lower in more densely planted management systems. They also showed the greater efficiency of simple practices of cutting weeds and grasses and maintaining vegetation cover to protect soil against water erosion compared to management systems with hoeing or tillage that exposes soils.

Thus, modeling or estimation of soil losses and identification of the areas most affected by water erosion are fundamental for evaluating the stage of degradation of intensely cultivated soils, such as coffee. These data allow to determine the best practices of soil use and management, with a view to reducing the areas degraded by erosion. In this context, the present study estimates potential soil losses by water erosion with RUSLE and compares them to the T limits in Oxisols (*Latossolos Vermelhos Distróficos*) under coffee crops in the Córrego da Laje Hydrographic Sub-basin in the municipality of Alfenas in the south of Minas Gerais, southeastern Brazil.

MATERIALS AND METHODS

This study was carried out from March 2015 to January 2017 in the Córrego da Laje Hydrographic Sub-basin, a direct tributary of the Furnas Hydroelectric Plant Reservoir, belonging to the Rio Grande Hydrographic Basin (Figure 1a). The area is located on the Capoeirinha Farm of the *Ipanema Agrícola SA* company (Ipanema Coffees) in the south of the municipality of Alfenas, southern Minas Gerais, southeastern Brazil. The sub-basin occupies 437 ha and is delimited by the coordinates UTM 23K 402000 to 405000 m E and 7616700 to 7620200 m N, Datum SIRGAS 2000, with altitudes from 814 to 914 m. The climate, according to the Köppen classification system, is mesothermal tropical (CwB), with annual average rainfall of 1,500 mm (Sparovek et al., 2007).

The geological framework of the area includes garnet-biotite gneisses and biotite gneisses overlaid by quaternary soils and unconsolidated deposits of gravel, sand, and mud (Ribeiro et al., 2010). To create the soil use map, Landsat-8 Thematic Mapper (TM) satellite imagery was used in the TM6, TM5, and TM4 bands, corresponding to orbit/point 219/75, obtained from the United States Geological Survey (USGS, 2016) and from the cartographic base of Capoeirinha Farm with soil use mapped by *Ipanema Agrícola SA* (Ipanema Coffees). Treatment, correction, and composition of the image were performed in ArcGis 10.2 (ESRI, 2014). The Google Earth image of Capoeirinha Farm (Google, 2015) and ground truthing were also used. The digital soil map was elaborated from the topography as the base attribute of soil formation (Mcbratney et al., 2003), together with field morphological descriptions and physical and chemical analyses performed at the Laboratories of the Department of Soil Science of the Federal University of Lavras (UFLA). First, a digital elevation model with cell (pixel) side length of approximately 10 m was generated from interpolation of the Topographic Chart contours of the municipality of Alfenas (Folha SF 23-1-1-3) on a 1:50,000 scale (IBGE, 1970) with the Topo to Raster tool of the ArcGis 10.2 application (ESRI, 2014). Then, the slope map (Figure 1c) was obtained by the ArcGis 10.2 Slope tool (ESRI, 2014), which guided the fieldwork.

Soils were collected and described according to Santos et al. (2005) and were classified according to Santos et al. (2013). In each of the three relief classes (slightly rolling, rolling,

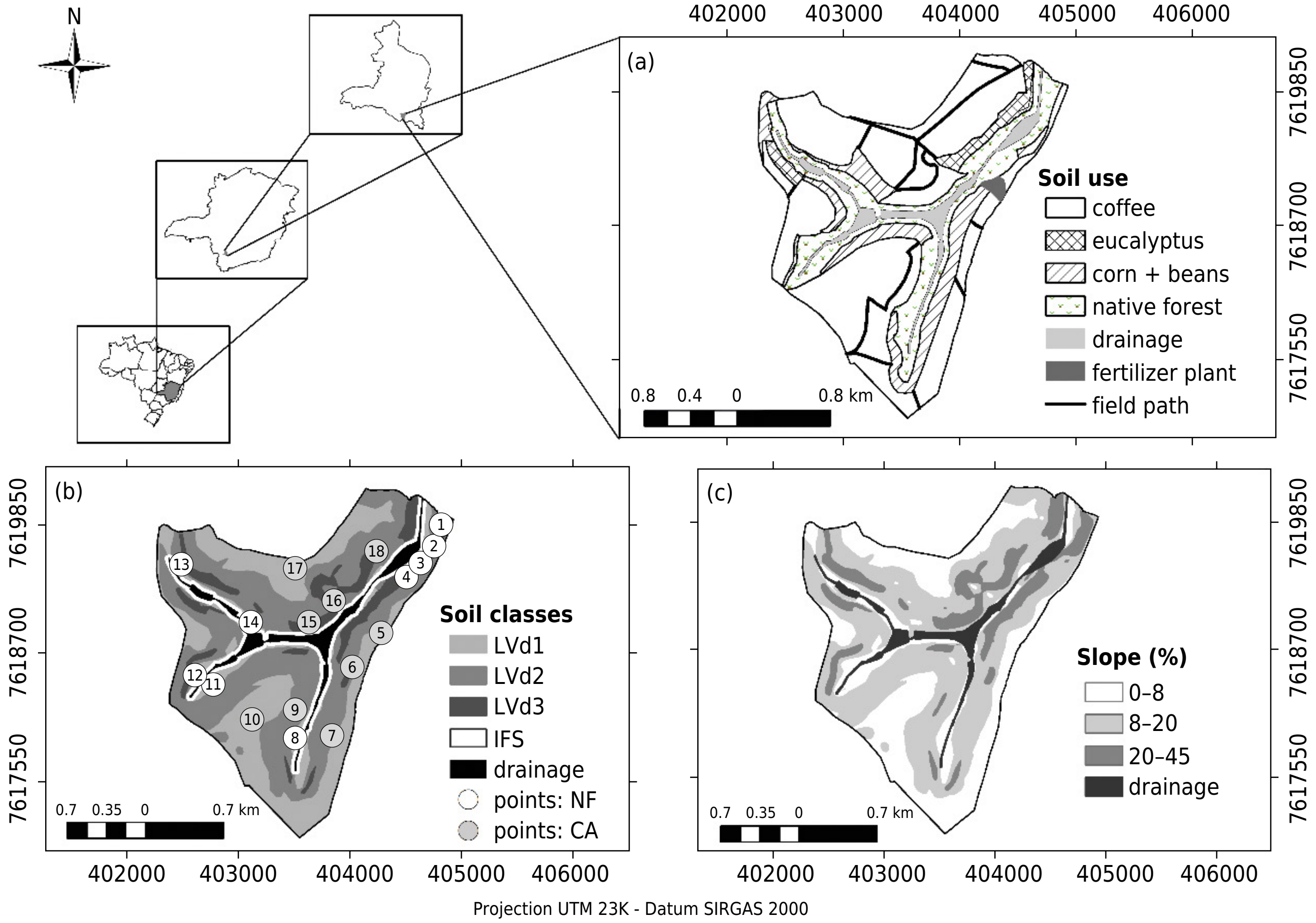

Figure 1. Map of the location of the Córrego da Laje Hydrographic Sub-basin, Alfenas, MG, and its current use (a); map of soils with soil collection sites in native forest (NF) and the coffee crop (CA), with the following soil classes: Oxisols (*Latossolos Vermelhos Distróficos*) in flat to slightly rolling (LVd1), rolling (LVd2), and strongly rolling (LVd3) relief; indiscriminate floodplain soils (IFS) (b); and slope map (c).

and strongly rolling), six samples were collected, three under the coffee crop and three under native forest, in the surface (0.00-0.20 m) and subsurface (0.20-0.60 m) layers (Figure 1b). For each layer, three types of samples were collected: disturbed, undisturbed in the shape of a clod, and undisturbed with a cylinder sampler (92.53 cm^3, 5 cm height).

The chemical and physical analyses performed were: particle size analysis by the pipette method, with and without the 0.1 mol L^{-1} NaOH dispersant (Gee and Bauder, 1986), and soil organic matter by oxidation with 2 mol L^{-1} $Na_2Cr_2O_7$ + 5 mol L^{-1} H_2SO_4 (Donagema et al., 2011). Morphological descriptions of the soils were determined from 18 small soil pits of 0.40 × 0.40 × 0.60 m and codification of soil properties according to Silva et al. (1999).

To determine the K factor of RUSLE and T, only the samples of the Oxisols (*Latossolos*) in the different relief classes (LVd1, LVd2, and LVd3) were considered, which were collected under native forest, where the natural attributes of the soil were unchanged.

Determination of RUSLE factors

Potential soil losses due to water erosion were estimated by RUSLE (Renard et al., 1997) (Equation 1):

$$A = R \times K \times LS \times C \times P \qquad \text{Eq. 1}$$

in which A = annual mean soil loss (Mg ha^{-1} yr^{-1}); R = rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}); K = soil erodibility factor (Mg h MJ^{-1} mm^{-1}); LS = topographic factor, which involves the length and steepness of the slope, dimensionless; C = soil use and management factor, dimensionless; and P = conservationist practices, dimensionless. The rainfall erosivity factor (R) considered was 6,500 MJ mm ha^{-1} h^{-1} yr^{-1}, which was about halfway between the 5,145 and 7,776 MJ mm ha^{-1} h^{-1} yr^{-1} obtained for the southern region of Minas Gerais by Aquino et al. (2012). The K factor was obtained from the descriptions and analyses of the soils by the indirect method of Silva et al. (1999), with model number 1, which, among the five proposed for Brazilian Oxisols (*Latossolos*), has the largest r^2 (0.98) and works with variables easily obtained in the field or in standard Brazilian laboratories. Model 1 is obtained by equation 2:

$$Y = 4.77 \times 10^{-2} - 9.66 \times 10^{-3} X_{14} + 1.63 \times 10^{-2} X_{16} - 1.12 \times 10^{-2} X_{17} + 1.85 \times 10^{-2} X_{18} - 1.51 \times 10^{-2} X_{19} - 2.46 \times 10^{-4} X_{22} - 3.58 \times 10^{-4} X_{23} + 1.47 \times 10^{-4} X_{24} - 1.43 \times 10^{-4} X_{25} + 3.26 \times 10^{-3} X_{26} - 1.26 \times 10^{-3} X_{27} - 2.29 \times 10^{-4} X_{31} + 1.07 \times 10^{-4} X_{32} + 2.69 \times 10^{-4} X_{34} \qquad \text{Eq. 2}$$

in which Y = erodibility (Mg h MJ^{-1} mm^{-1}); X_{14} = code of the hue of the moist soil according to Munsell (dimensionless); X_{16} = structure degree code (dimensionless); X_{17} = structure size code (dimensionless); X_{18} = structure shape code (dimensionless); X_{19} = soil plasticity code (dimensionless); X_{22} = fine sand content dispersed in 0.1 mol L^{-1} NaOH (g kg^{-1}); X_{23} = very fine sand content dispersed in 0.1 mol L^{-1} NaOH (g kg^{-1}); X_{24} = silt content dispersed in 0.1 mol L^{-1} NaOH (g kg^{-1}); X_{25} = clay content dispersed in 0.1 mol L^{-1} NaOH (g kg^{-1}); X_{26} = very coarse sand content dispersed in water (g kg^{-1}); X_{27} = coarse sand content dispersed in water (g kg^{-1}); X_{31} = silt content dispersed in water (g kg^{-1}); X_{32} = clay content dispersed in water (g kg^{-1}); and X_{34} = flocculation index (dimensionless).

The values of the K factor and the variables used in calculation of erodibility are presented in table 1. The color (when moist) of the soil showed hue 2.5 YR for the soil classes. The structure was characterized as strong and medium in subangular blocks for classes LVd1 and LVd2; and as weak and small in subangular blocks for LVd3. The consistency of the moist soil was slightly plastic for LVd1 and LVd2, and plastic for LVd3.

The topographic factor (LS) was determined by the $LS_{RUSLE\ 3D}$ model of Mitasova et al. (2001) from equation 3, and calculation was performed in Map Algebra of ArcGis 10.2 (ESRI, 2014):

$$LS_{RUSLE\ 3D} = (m + 1)\ (A/22.13)^m\ (sen\theta/0.09)^n \qquad \text{Eq. 3}$$

in which: $LS_{RUSLE\ 3D}$ = topographic factor (dimensionless); A = upslope contribution area per unit of cell length for an MDE (m²); θ = inclination angle of the slope (degrees); and m and n = empirical parameters, with m ranging from 0.4 to 0.6 and n ranging from 1.0 to 1.4, depending on the predominant type of erosion (laminar or gullies). The values of the m and n parameters were 0.4 and 1.0, respectively, for the predominant type of erosion, which was laminar. The slope angle (θ) was derived from the slope map (Figure 1c) and converted to degrees. Variable A was obtained by further processing of the MDE in ArcGis 10.2 (ESRI, 2014) with the deterministic infinity (D ∞) algorithm (Tarboton, 1997) of the TauDEM 5.1.2 tool set (Tarboton and Mohammed, 2014).

Factor C values indicate the effects of crop practices and associated practices on soil erosion rates. Factor C ranges from 1 for exposed soils to 0.015 for native forest (Silva et al., 2016). The values of C decrease as the soil cover increases, which implies a lower rate of soil erosion. The values of C were obtained from the literature (Table 2) for the following classes of land use: coffee (237.35 ha); annual corn (October/April) and edible bean (May/September) crops (60.49 ha); eucalyptus (16.95 ha); permanent preservation area (PPA) (90.59 ha); field paths (field dividers) (9.71 ha); fertilizer plant (2.40 ha); and drainage areas (19.51 ha) (Figure 1a). The PPA corresponds to 20.73 % of the sub-basin and is in accordance with the Brazilian Forest Code (Brasil, 2012), respecting 50 m distance

Table 1. Values of K factor, of variables for indirect calculation of erodibility, and of input to obtain soil loss tolerance (T)

Variable	Description	Value		
		LVd1	LVd2	LVd3
K factor	Soil erodibility (Mg h MJ^{-1} mm^{-1})	0.021	0.004	0.026
X_{14}	Moist soil hue code according to Munsell (dimensionless)	2.000	2.000	2.000
X_{16}	Structure degree code (dimensionless)	3.000	3.000	2.000
X_{17}	Structure size code (dimensionless)	3.000	3.000	2.000
X_{18}	Structure shape code (dimensionless)	2.000	2.000	2.000
X_{19}	Soil plasticity code (dimensionless)	2.000	2.000	3.000
X_{22}	FS content dispersed with 0.1 mol L^{-1} NaOH (g kg^{-1})	92.000	88.500	97.000
X_{23}	VFS content dispersed with 0.1 mol L^{-1} NaOH (g kg^{-1})	27.000	24.000	28.500
X_{24}	Silt content dispersed with 0.1 mol L^{-1} NaOH (g kg^{-1})	109.000	72.000	107.000
X_{25}	Clay content dispersed with 0.1 mol L^{-1} NaOH (g kg^{-1})	602.000	607.000	584.000
X_{26}	VCS content dispersed in water (g kg^{-1})	24.000	28.500	37.000
X_{27}	CS content dispersed in water (g kg^{-1})	77.000	99.000	77.000
X_{31}	Silt content dispersed in water (g kg^{-1})	173.500	160.500	165.500
X_{32}	Clay content dispersed in water (g kg^{-1})	405.500	417.000	443.500
X_{34}	Flocculation index (dimensionless)	327.000	313.000	240.600
T	Soil loss tolerance (Mg ha^{-1} yr^{-1})	5.190	5.690	5.900
h	Effective soil depth (mm)	1.000	1.000	1.000
r_a	Textural relationship between the B and A horizons and the clay content of the A horizon (g kg^{-1})	1.060	1.030	0.970
m	Organic matter in the 0.00-0.20 m soil layer (g kg^{-1})	24.500	16.600	20.100
p	Soil permeability (mm h^{-1})	10.190	1.111	5.897
d	Soil Bulk Density (Mg m^{-3})	1.060	1.160	1.205

Relief of Oxisol (*Latossolos Vermelhos Distróficos*): flat and slightly rolling (LVd1), rolling (LVd2), and strongly rolling (LVd3). FS = fine sand; VFS = very fine sand; VCS = very coarse sand; CS = coarse sand. Source: Silva et al. (1999).

Table 2. The C and P factors for uses and management practices verified

Use and management practices	C Factor	P factor[(1)]
Coffee spaced at 3.0 × 0.5 m and contour planting	0.1354 (Prochnow et al., 2005)	0.50
Corn + edible beans with no-till planting	0.0271 (Bertol et al., 2001)	0.01
Eucalyptus	0.1240 (Silva et al., 2016)	1.00
Native forest	0.0150 (Silva et al., 2016)	0.01
Field path (field divider)	1.0000[(2)]	1.00

(1) P values obtained from Bertoni and Lombardi Neto (2012). (2) Maximum C value for exposed soils.

around springs and 30 m distance from the banks of watercourses. The native forest area considered in the soil loss calculations was 68.99 ha. A weir with a mean width of 40 m was used as a source for drip fertigation of coffee, drastically attenuating the erosive effects of intensive irrigation. The area of the fertilizer plant, with soil impermeable to water, was not considered in the soil loss calculations.

The area was cultivated with arabica coffee (*Coffea arabica* L.) in 1994/1995 and 2001/2002, with mean plant spacing of 3.95 × 0.55 m. Due to the absence of C factor values for coffee cultivation in Oxisols (*Latossolos*), the closest C factor was used for this spacing (Prochnow et al., 2005), derived from coffee cultivated in Ultisol (*Argissolo*) with a spacing of 3.00 × 0.50 m. However, we may have underestimated potential soil losses in coffee cultivation due to smaller spacing in the area than that used in the calculation.

Temporary crops were corn (October/April) followed by edible bean (May/September). Due to the absence of C factor data for edible bean in the literature, the value for soybean was used (Bertol et al., 2001) according to Ayer et al. (2015), who calculated the C factor by the weighted average of rainfall erosivity for soybean plus corn, instead of corn and edible bean. The use of the C factor of soybean instead of edible bean is justified by the physical and canopy cover similarities of the two plants (Roloff and Bertol, 1998).

For the P factor, the conservation practices observed in the area and the values obtained by Bertoni and Lombardi Neto (2012) were used (Table 2). The coffee was cultivated in contour lines, with planting in contours, and corne and edible bean were cultivated with no tillage. For eucalyptus, a conservationist practice was not adopted, as it was characterized by planting down the hill, that is, planting that did not follow the contour lines (Pruski, 2009). Native forest was assigned the lowest value, due to the low rates of natural erosion.

Soil losses by RUSLE were calculated with Map Algebra and Zonal Statistics as Table of ArcGis 10.2 (ESRI, 2014).

Determination of soil loss tolerance

Soil loss tolerance, according to the method of Bertol and Almeida (2000), was obtained by equation 4.

$$T = h\ r_a\ m\ p\ 1.000^{-1} \qquad \text{Eq. 4}$$

in which: T = soil loss tolerance (Mg ha^{-1} yr^{-1}), corrected from the original equation considering soil bulk density; h = effective soil depth (mm), limited to 1,000 mm; r_a = relationship that expresses, at the same time, the effect of the textural relationship between the B and A horizons and the clay content of the A horizon; m = factor that expresses the effect of the organic matter in the top 0.20 m of the soil; p = factor that expresses the effect of soil permeability; and $1{,}000^{-1}$ = constant that expresses the time period required to wear away a soil layer of 1,000 mm thickness. The effective depth (h) of the Oxisols (*Latossolos*) ranges from 1,500 to 2,000 mm, as determined by soil profiles examined in the study area and from literature on the region (Brasil, 1962). Thus, the value used for the variable h for all soil classes was 1,000 mm. The variable r_a used the content of clay dispersed in 0.1 mol L^{-1} NaOH, which ranged from 584 to 607 g kg^{-1}. Thus, the textural relationship between the subsurface (0.20-0.60 m) and surface layers (0.00-0.20 m) of each sample was obtained first (Santos et al., 2013). The variable m represents the average organic matter content in the surface layer (0.00-0.20 m) of each soil class. The soil permeability variable p was obtained in the field, from three replicates for each soil class (Zhang, 1997; Dane and Topp, 2002) with a Mini Disk infiltrometer (Decagon Devices, Pullman, WA, USA) adjusted for a suction rate of 2 cm. Soil permeability was classified according to Soil Survey Division Staff (1993) and Galindo and Margolis (1989), which use the texture and degree of soil structure. The input values of the T calculation for each soil class are shown in table 1.

Soil loss tolerance values were correlated to potential soil losses in ArcGis 10.2 (ESRI, 2014).

RESULTS AND DISCUSSION

The areas mapped as indiscriminate floodplain soil (IFS) were disregarded in estimation of soil losses because they are areas of sediment deposition (Mitasova et al., 2001; Olivetti et al., 2015). The texture of the Oxisols (*Latossolos*) was classified as clayey and very clayey, with a clay content between 58.40 and 60.70 %.

The value of the R factor, 6,500 MJ mm ha^{-1} h^{-1} yr^{-1}, was considered high and was influenced by the topography and regional climatic variation, with the highest erosivity associated with the highest altitudes. Thus, Aquino et al. (2012) recommend adoption of conservation practices in soil management, especially in rugged terrain, due to the effects of regional rainfall frequency, quantity, and intensity.

The erodibility factor was close to that of Silva et al. (1999, 2000), from 0.002 to 0.034 Mg h MJ^{-1} mm^{-1}. However, the LVd2 class had the lowest value, possibly due to exhibiting lower content of 0.1 mol L^{-1} NaOH dispersed silt (variable X_{24}), at 72.0 g kg^{-1} (Table 1).

Topographic factor (LS) ranged from 0 to 3.883, with an average of 0.318. These results demonstrate that the $LS_{RUSLE\ 3D}$ model was effective in determining the topographic factor because the highest values were obtained on the steepest slopes with intense accumulated flow.

Factors C and P (Table 2), with values close to 1.0, showed less vegetation protection against erosion, either due to the lower density of plant cover or the lack of conservation management practices. The highest values were identified in the coffee field paths because the soil was exposed and devoid of plant protection. Values of the C factor for coffee, corn (October/April), edible bean (May/September), and eucalyptus were below the average for arable land reported by Panagos et al. (2015c), which was 0.2330, possibly due to the different crops and lack of conservation management in much of the area they studied. The mean C factor of native forests was 0.015 (Table 2), higher than the 0.0012 of Panagos et al. (2015c) for European forest areas. In addition, the mean P factor obtained in that area was 0.9702, considered high by Panagos et al. (2015d), due to the small number of areas cultivated with conservation practices.

In the RUSLE model of water erosion, the average potential soil loss was 1.52 Mg ha^{-1} yr^{-1}. The average potential losses per land use class ranged from 0.01 to 18.77 Mg ha^{-1} yr^{-1} (Table 3).

In the soil loss map, adapted from Beskow et al. (2009), 83.93 % of the area had mild erosion and potential soil losses from 0 to 2.5 Mg ha^{-1} yr^{-1} (Figure 2a). These results show the effectiveness of soil management, especially in coffee crops planted on the contour, which occupy 54.31 % of the area. However, 6.10 % of the sub-basin had moderate to extremely severe erosion, with potential soil losses of 2.5 to more than 100 Mg ha^{-1} yr^{-1}. Therefore, these areas are a priority for adoption of conservation practices to mitigate soil losses.

The highest potential average soil losses were concentrated in the coffee field paths, at 18.77 Mg ha^{-1} yr^{-1}, which also accounted for 27.28 % of potential losses. This was due

Table 3. Values of potential soil losses only in the soil use classes

Soil use class	Area		Average soil loss	Total soil loss	Contribution to total soil loss
	ha	%	Mg ha^{-1} yr^{-1}	Mg yr^{-1}	%
Coffee	237.35	54.31	1.58	375.01	56.12
Corn + Edible beans	60.49	13.84	0.12	7.26	1.08
Eucalyptus	16.95	3.88	6.08	103.05	15.42
Native forest(1)	68.99	15.78	0.01	0.69	0.10
Field paths	9.71	2.22	18.77	182.25	27.28
Fertilizer plant	2.40	0.55	-	-	-
Drainage	19.51	4.47	-	-	-
Area of deposition	21.60	4.95	-	-	-
Total	437.00	100	1.52(2)	668.26	100

(1) Native forest area = permanent preservation area (PPA) added to the legal reserve area subtracted from the area of deposition. (2) Average amount of soil loss for the study area. -: not calculated.

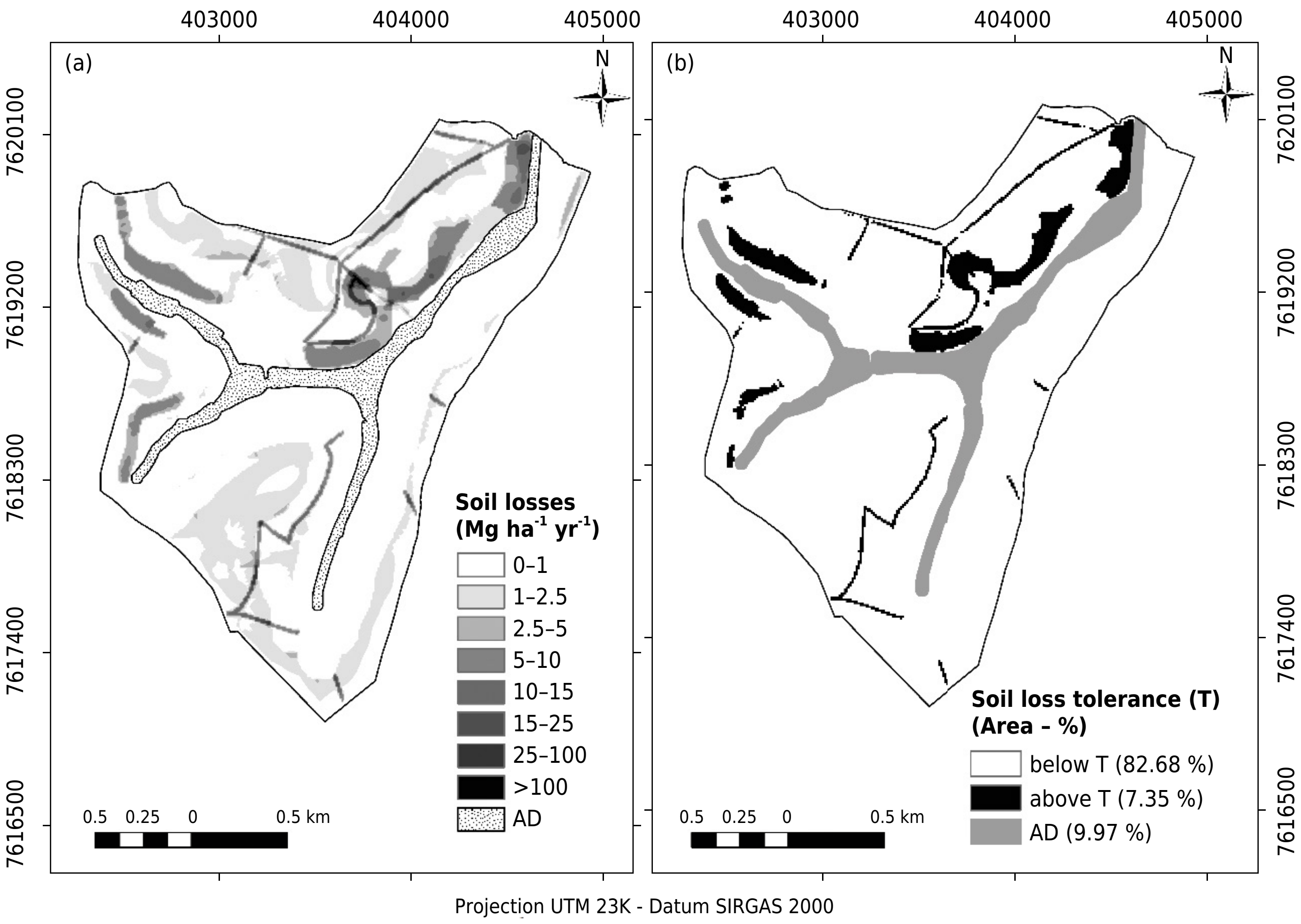

Figure 2. Map of classes of soil losses by water erosion (a). Map of the percentage of the areas below and above the soil loss tolerance limit (T) for the Córrego da Laje Hydrographic Sub-basin, Alfenas, MG (b). AD = area of deposition.

to the high C and P factors, which, in turn, were due to exposed soil, especially on the steep slopes (LS) (20-45 %). Such potential losses from higher soils are probably due to the intensive use of heavy machinery in production activities, which disrupt the soil, make water infiltration difficult, and contribute to removal of soil particles and losses by water runoff.

Corn (October/April) and edible bean (May/September) showed potential soil losses of 0.12 Mg ha^{-1} yr^{-1}, lower than the average of the sub-basin, due to the no-till conservation management adopted. These values were below those estimated by Ayer et al. (2015) in another area, due to the difference in P values used in the two studies, with values of 0.01 (Ayer et al., 2015) and 1.00 for this study. The practice of no-tillage contributes to decreased water erosion by using the trash from previous crops in the new crop, increasing soil protection, and incorporating organic matter that improves soil structure (Bertoni and Lombardi Neto, 2012).

The contribution of the eucalyptus crop to potential soil losses was 15.42 %, with a mean loss of 6.08 Mg ha^{-1} yr^{-1}. These values were higher than those found by Cândido et al. (2014) from 0.00 to 0.853 Mg ha^{-1} yr^{-1} in experimental plots in the eastern part of Mato Grosso do Sul. This discrepancy is likely due to planting eucalyptus down the hill, without conservation management, which increased the value of the P factor.

In the native forest, we estimated a potential average soil loss of 0.01 Mg ha^{-1} yr^{-1}, lower than the average of the sub-basin and similar to that of Silva et al. (2016), who obtained losses from 0.01 to 0.38 Mg ha^{-1} yr^{-1} in native forest in Rio Grande do Sul.

The average soil loss in coffee cultivation was 1.58 Mg ha^{-1} yr^{-1}. This value was lower than that estimated by Silva et al. (2007) for the Oxisol (*Latossolo Vermelho-Amarelo*) with conilon coffee (*Coffea canephora* Pierre ex Froehner) at a spacing of 2.90 × 0.90 m cultivated for five years in Cachoeiro de Itapemirim, Espírito Santo, which was 10.98 Mg ha^{-1} yr^{-1}. The discrepancy is due to differences in soil erodibility, which was 0.14 Mg h MJ^{-1} mm^{-1} in Silva et al. (2007) but was 0.004-0.026 Mg h MJ^{-1} mm^{-1} in this study, with values of C and P factors based on Prochnow et al. (2005). Therefore, the soils studied show less susceptibility to water erosion. In addition, the planting of coffee in the sub-basin was performed on the contour, with a P value of 0.50, which helped to reduce potential soil losses. Mean values of potential soil losses from 0.11 to 0.28 Mg ha^{-1} yr^{-1} were obtained by Carvalho et al. (2007) for coffee under different management systems in the south of Minas Gerais, at a spacing of 3.00 × 0.75 m in experimental plots. These lower soil losses can be explained by the different and varied management practices adopted.

The T values were 5.19, 5.69, and 5.90 Mg ha^{-1} yr^{-1} for the soils LVd1, LVd2, and LVd3, respectively. These results indicate that 7.35 % of the area presented potential soil losses above the T limit (Figure 2b). The results for T were lower than those obtained by Bertol and Almeida (2000) for an Oxisol (*Latossolos Vermelho escuro*) in the state of Santa Catarina, which were from 10.62 to 12.50 Mg ha^{-1} yr^{-1}. One possible explanation is the low weighted values of the organic matter content and of the degree of soil permeability, which were both 0.70 in this study. In addition, the values are lower than those estimated by Lombardi Neto and Bertoni (1975) for soils with an Oxisol B horizon *(horizonte B latossólico)* in the state of São Paulo, which were from 9.60 to 15.00 Mg ha^{-1} yr^{-1}. This difference may be because the method of Bertol and Almeida (2000) considered more soil properties in estimating T. Therefore, the T estimate by the Bertol and Almeida (2000) method is more restrictive and more conservationist for the soil.

The results obtained show efficiency in the management of coffee, corn, and edible bean, with potential soil losses below the limits of T. However, in areas with steeper slopes, it is recommended to use conservation practices that increase soil protection against erosion. Even considering that these areas are protected by the Forest Code as permanent protection areas, their utilization, as in this case, is permitted only for activities consolidated up to July 22, 2008 (Brasil, 2012). In such areas, terracing is an alternative because it reduces runoff and consequent transport of soil (Bertoni and Lombardi Neto, 2012). In addition, it contributes to conservation of the water in dams and watercourses, avoiding silting and reducing inputs for fertilization of the crops.

The greatest potential losses of soils occur in the field paths that are the access routes necessary for maintaining production activities. In view of this, adoption of catchment areas for surface runoff waters is recommended for the steeper sloped areas of these routes. This practice would reduce potential soil losses by reducing the effect of the runoff and would promote increased water infiltration and groundwater supply (Barros, 2000). In addition, application of gravel over the entire length of the roads can increase the erosion resistance of road surfaces.

Planting eucalyptus downhill is one of the main soil degradation factors in the area, favoring the effects of water erosion. Thus, it is recommended that new plantations be made with conservationist practices, that is, following the contour lines, with greater plant density and terracing in more sloped areas, as well as cutting of spontaneous plant growth between the crops without exposing the soil.

The modeling of soil losses by RUSLE in the Córrego da Laje Hydrographic Sub-basin has shown, above all, that the exposed soil in access roads, especially on steeper slopes, is the main conditioning factor for an increase in potential soil losses due to erosion above the T limits.

In the context of water erosion modeling, Amorim et al. (2010) evaluated the performance of prediction models by comparison with experimental plot data and noted that the efficiencies of prediction models of soil losses are better in areas with higher potential soil losses. Therefore, in the water erosion model, the results of the soil losses obtained should be taken only as indicative because they were not verified in the field nor validated, which limits the conclusions of this study. This indicates the need for new research that models erosion by using experimentally validated data, aiming to refine the results and adopt methodological innovations of evaluation and monitoring of soil losses (Zolin et al., 2011). Despite the limitations of modeling, the potential erosion data obtained by RUSLE indicated the areas that had the highest rates of soil loss and lacked soil conservation measures.

CONCLUSIONS

Conservation practices used in coffee crops and annual corn (October/April) and edible bean (May/September) crops are efficient to keep potential erosion rates lower than soil loss tolerance.

The absence of conservation practices increases potential soil losses of the area to rates much higher than the soil loss tolerance, compromising the sustainability of activities.

Areas with steeper slopes and consolidated use, with absence of conservation practices, lead to an increase in potential soil losses above the soil loss tolerance level, making these areas a priority for adoption of measures that mitigate erosive effects

The revised universal soil loss equation can model water erosion and identify the areas with the highest rates of potential soil loss quickly and help subsidize soil conservation in drainage basins.

When properly used, erosion prediction models, in spite of their quantitative limitations and the need to gauge the erosion data, can reduce the costs and time required to evaluate the land use and management factors affecting erosive processes.

ACKNOWLEDGMENTS

The authors thank the Laboratory of Soil Analysis of the Department of Soil Science of the Federal University of Lavras for support and assistance in soil analysis; *Ipanema Agrícola SA* (Ipanema Coffees) for the partnership, trust, financing of soil laboratory analyses and logistical support in field work; FAPEMIG (project CAG-APQ 01053-15); and CNPq (project No. 306511/2017-7).

REFERENCES

Amorim RSS, Silva DD, Pruski FF, Matos AT. Avaliação do desempenho dos modelos de predição da erosão hídrica USLE, RUSLE e WEPP para diferentes condições edafoclimáticas do Brasil. Eng Agric. 2010;30:1046-59. https://doi.org/10.1590/S0100-69162010000600006

Aquino RF, Silva MLN, Freitas DAF, Curi N, Mello CR, Avanzi JC. Spatial variability of the rainfall erosivity in Southern region of Minas Gerais State, Brazil. Cienc Agrotec. 2012;36:533-42. https://doi.org/10.1590/S1413-70542012000500006

Avanzi JC, Silva MLN, Curi N, Norton LD, Beskow S, Martins SG. Spatial distribution of water erosion risk in a watershed with eucalyptus and Atlantic Forest. Cienc Agrotec. 2013;37:427-34. https://doi.org/10.1590/S1413-70542013000500006

Ayer JEB, Olivetti D, Mincato RL, Silva MLN. Erosão hídrica em Latossolos Vermelhos distróficos. Pesq Agropec Trop. 2015;45:180-91. https://doi.org/10.1590/1983-40632015v4531197

Barros LC. Captação de águas superficiais de chuvas em barraginhas. Sete Lagoas: Embrapa Milho e Sorgo; 2000. (Circular técnica, 2).

Bertol I, Almeida JA. Tolerância de perda de solo por erosão para os principais solos do estado de Santa Catarina. Rev Bras Cienc Solo. 2000;24:657-68. https://doi.org/10.1590/S0100-06832000000300018

Bertol I, Schick J, Batistela O. Razão de perdas de solo e fator C para as culturas de soja e trigo em três sistemas de preparo em um Cambissolo Húmico alumínico. Rev Bras Cienc Solo. 2001;25:451-61. https://doi.org/10.1590/S0100-06832001000200021

Bertoni J, Lombardi Neto F. Conservação do solo. 8. ed. São Paulo: Ícone Editora; 2012.

Beskow S, Mello CR, Norton LD, Curi N, Viola MR, Avanzi JC. Soil erosion prediction in the Grande River Basin, Brazil using distributed modeling. Catena. 2009;79:49-59. https://doi.org/10.1016/j.catena.2009.05.010

Brasil. Código Florestal. Lei n° 12.651 de 25 de maio de 2012 [internet]. Brasília, DF: Casa Civil, Subchefia para Assuntos Jurídicos; 2012 [acesso em 15 mai 2015]. Disponível em: http://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/l12651.htm.

Brasil. Ministério da Agricultura. Levantamento de reconhecimento dos solos da região sob influência do reservatório de Furnas. Rio de Janeiro: Centro Nacional de Ensino e Pesquisas Agronômicas; 1962. (Boletim, 13).

Cândido BM, Silva MLN, Curi N, Batista PVG. Erosão hídrica pós-plantio em florestas de eucalipto na bacia do Rio Paraná, no leste do Mato Grosso do Sul. Rev Bras Cienc Solo. 2014;38:1565-75. https://doi.org/10.1590/S0100-06832014000500022

Carvalho R, Silva MLN, Avanzi JC, Curi N, Souza FS. Erosão hídrica em Latossolo Vermelho sob diversos sistemas de manejo do cafeeiro no sul de Minas Gerais. Cienc Agrotec. 2007;31:1679-87. https://doi.org/10.1590/S1413-70542007000600012

Clark EV, Odhiambo BK, Yoon S, Pilati L. Hydroacoustic and spatial analysis of sediment fluxes and accumulation rates in two Virginia reservoirs, USA. Environ Sci Pollut Res. 2015;22:8659-71. https://doi.org/10.1007/s11356-014-4050-x

Dane JH, Topp CG. Methods of soil analysis: Physical methods. 3rd ed. Madison: Soil Science Society of America; 2002. Pt. 4.

Dechen SCF, Telles TS, Guimarães MF, De Maria IC. Perdas e custos associados à erosão hídrica em função de taxas de cobertura do solo. Bragantia. 2015;74:224-33. https://doi.org/10.1590/1678-4499.0363

Donagema GK, Campos DVB, Calderano SB, Teixeira WG, Viana JHM. Manual de métodos de análise do solo. 2. ed. rev. Rio de Janeiro: Embrapa Solos; 2011.

Environmental Systems Research Institute - ESRI. ArcGIS Professional GIS for the desktop [computer program]. Version 10.2. Redlands, CA: Environmental Systems Research Institute; 2014.

Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils - FAO, ITPS. Status of the world’s soil resources (SWSR) - technical summary. Rome: FAO, ITPS; 2015.

Galindo ICL, Margolis E. Tolerância de perdas por erosão para solos do estado de Pernambuco. Rev Bras Cienc Solo. 1989;13:95-100.

Gavrilovic Z. The use of an Empirical Method (Erosion Potential Method) for calculating sediment production and transportation in unstudied or torrential Streams. In: International Conference on River Regime Hydraulics Research Limited; 1988 May 18-20; Oxon, United Kingdom. Wallingford: Hydraulics Research Limited; 1988. p. 411-22.

Gee GW, Bauder JW. Particle-size analysis. In: Klute A, editor. Methods of soil analysis: physical and mineralogical methods. 2nd ed. Madison: American Society of Agronomy; 1986. Pt 1. p. 383-411.

Google. Google Earth. Version 7.1.4.1529. 2015 [accessed on 2015 Aug 4]. Available at: http://www.google.com.br/earth/download/gep/agree.html.

Instituto Brasileiro de Geografia e Estatística - IBGE. Carta topográfica do município de Alfenas (Folha SF 23-1-1-3), escala 1:50000. Rio de Janeiro: IBGE; 1970.

Karydas CG, Panagos P, Gitas IZ. A classification of water erosion models according to their geospatial characteristics. Int J Digit Earth. 2014;7:229-50. https://doi.org/10.1080/17538947.2012.671380

Lombardi Neto F, Bertoni J. Tolerância de perdas de terra para solos do estado de São Paulo. Campinas: Instituto Agronômico; 1975. (Boletim Técnico, 28).

McBratney AB, Santos MLM, Minasny B. On digital soil mapping. Geoderma. 2003;117:3-52. https://doi.org/10.1016/S0016-7061(03)00223-4

Mitasova HM, Mitas L, Brown WM, Johnston DM. Terrain modelling and soil erosion: applications for Ft. Hood report for USA CERL. Champaign: University of Illinois; 2001 [accessed on 2016 May 17]. Available at: http://www4.ncsu.edu/~hmitaso/gmslab/reports/cerl01/finalreport/report01/default.htm#1.

Morgan RPC, Nearing MA. Handbook of erosion modeling. West Sussex: Wiley-Blackwell; 2011.

Morgan RPC, Quinton JN, Smith RE, Govers G, Poesen JWA, Auerswald K, Chisci G, Torri D, Styczen ME. The European soil erosion model (EUROSEM): a dynamic approach for predicting sediment transport from fields and small catchments. Earth Surf Process Landforms. 1998;23:527-44. https://doi.org/10.1002/(SICI)1096-9837(199806)23:6<527::AID-ESP868>3.0.CO;2-5

Nearing MA, Foster GR, Lane LJ, Flinkner SC. A process-based soil erosion model for USDA - water erosion prediction project technology. T Asae. 1989;32:1587-93. https://doi.org/10.13031/2013.31195

Oliveira FG, Seraphim OJ, Borja MEL. Estimativa de perdas de solo e do potencial natural de erosão da bacia de contribuição da Microcentral Hidrelétrica do Lageado, Botucatu - SP. Energ Agric. 2015;30:302-9. https://doi.org/10.17224/EnergAgric.2015v30n3p302-309

Olivetti D, Mincato RL, Ayer JEB, Silva MLN, Curi N. Spatial and temporal modeling of water erosion in dystrophic Red Latosol (Oxisol) used for farming and cattle raising activities in a sub-basin in the south of Minas Gerais. Cienc Agrotec. 2015;39:58-67. https://doi.org/10.1590/S1413-70542015000100007

Panagos P, Borrelli P, Meusburger K. A new European slope length and steepness factor (LS-Factor) for modeling soil erosion by water. Geosciences. 2015a;5:117-26. https://doi.org/10.3390/geosciences5020117

Panagos P, Borrelli P, Meusburger K, Alewell C, Lugato E, Montanarella L. Estimating the soil erosion cover-management factor at the European scale. Land Use Policy. 2015c;48:38-50. https://doi.org/10.1016/j.landusepol.2015.05.021

Panagos P, Borrelli P, Meusburger K, van der Zanden EH, Poesen J, Alewell C. Modelling the effect of support practices (P-factor) on the reduction of soil erosion by water at European scale. Environ Sci Policy. 2015d;51:23-34. https://doi.org/10.1016/j.envsci.2015.03.012

Panagos P, Borrelli P, Poesen J, Ballabio C, Lugato E, Meusburger K, Montanarella L, Alewell C. The new assessment of soil loss by water erosion in Europe. Environ Sci Policy. 2015b;54:438-47. https://doi.org/10.1016/j.envsci.2015.08.012

Pimentel D. Soil erosion: a food and environmental threat. Environ Dev Sustain. 2006;8:119-37. https://doi.org/10.1007/s10668-005-1262-8

Pimentel D, Harvey C, Resosudarmo P, Sinclair K, Kurz D, McNair M, Crist S, Shpritz L, Fitton L, Saffouri R, Blair R. Environmental and economic costs of soil erosion and conservation benefits. Science. 1995;267:1117-23. https://doi.org/10.1126/science.267.5201.1117

Prochnow D, Dechen SCF, De Maria IC, Castro OM, Vieira SR. Razão de perdas de terra e fator C da cultura do cafeeiro em cinco espaçamentos, em Pindorama (SP). Rev Bras Cienc Solo. 2005;29:91-8. https://doi.org/10.1590/S0100-06832005000100010

Pruski FF. Conservação de solo e água: práticas mecânicas para o controle da erosão hídrica. 2nd ed. Viçosa, MG: Universidade Federal de Viçosa; 2009.

Renard KG, Foster GR, Weesies GA, McCool DK, Yoder DC. Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE). Washington, DC: USDA; 1997. (Agricultural Handbook, 703).

Ribeiro A, Campos MT, Paciullo FV, Carvalho MV, Valeriano C, Nascimento D. Mapa geológico: folha Alfenas (SF-23-V-D-II), escala 1:100.000. Rio de Janeiro: Universidade Federal do Rio de Janeiro, Companhia de Pesquisa de Recursos Minerais; 2010.

Roloff G, Bertol OJ. Método para a estimativa da cobertura do solo e da altura do dossel de algumas culturas de verão. Rev Bras Cienc Solo. 1998;22:319-27. https://doi.org/10.1590/S0100-06831998000200018

Santos HG, Jacomine PKT, Anjos LHC, Oliveira VA, Oliveira JB, Coelho MR, Lumbreras JF, Cunha TJF. Sistema brasileiro de classificação de solos. 3. ed. rev. ampl. Rio de Janeiro: Embrapa Solos; 2013.

Santos RD, Lemos RC, Santos HG, Ker JC, Anjos LHC. Manual de descrição e coleta de solo no campo. 5. ed. rev. ampl. Viçosa, MG: Sociedade Brasileira de Ciência do Solo; 2005.

Silva AM, Schulz HE, Camargo PB. Erosão e hidrossedimentalogia em bacias hidrográficas. 2. ed. São Carlos: Rima; 2007.

Silva BPC, Silva MLN, Batista PVG, Pontes LM, Araújo EF, Curi N. Soil and water losses in eucalyptus plantation and natural forest and determination of the USLE factors at a pilot sub-basin in Rio Grande do Sul, Brazil. Cienc Agrotec. 2016;40:432-42. https://doi.org/10.1590/1413-70542016404013216

Silva MLN, Curi N, Ferreira MM, Lima JM, Ferreira DF. Proposição de modelos para estimativa da erodibilidade de Latossolos brasileiros. Pesq Agropec Bras. 1999;34:2287-98. https://doi.org/10.1590/S0100-204X1999001200016

Silva MLN, Curi N, Lima JM, Ferreira MM. Avaliação de métodos indiretos de determinação da erodibilidade de Latossolos brasileiros. Pesq Agropec Bras. 2000;35:1207-20. https://doi.org/10.1590/S0100-204X2000000600018

Soil Survey Division Staff. Soil survey manual. Washington, DC: United States Department of Agriculture, Natural Resources Conservation Service; 1993. (Agriculture Handbook 18).

Sparovek G, Jong van Lier Q, Dourado Neto D. Computer assisted Koeppen climate classification: a case study for Brazil. Int J Climatol. 2007;27:257-66. https://doi.org/10.1002/joc.1384

Tamene L, Le QB. Estimating soil erosion in sub-Saharan Africa based on landscape similarity mapping and using the revised universal soil loss equation (RUSLE). Nutr Cycl Agroecosyst. 2015;102:17-31. https://doi.org/10.1007/s10705-015-9674-9

Tarboton DG. A new method for the determination of flow directions and contributing areas in grid digital elevation models. Water Resour Res. 1997;33:309-19. https://doi.org/10.1029/96WR03137

Tarboton DG, Mohammed IN. Software TauDEM 5.1.2: terrain analysis using digital elevation models; 2014 [accessed on Jul 22, 2016]. Available at: http://hydrology.usu.edu/taudem/taudem5/downloads.html.

USGS, United States Geological Survey. EarthExplorer; 2016. [accessed on 2016 Feb 4]. Avalaible at: http://earthexplorer.usgs.gov.

Wischmeier WH, Smith DD. Predicting rainfall erosion losses: a guide to conservation planning. Washington, DC: USDA; 1978. (Agricultural handbook, 537).

Zhang, R. Determination of soil sorptivity and hydraulic conductivity from the disk infiltrometer. Soil Sci Soc Am J. 1997;61:1024-30. https://doi.org/10.2136/sssaj1997.03615995006100040005x

Zolin CA, Folegatti MV, Mingoti R, Sánchez-Román RM, Paulino J, Gonzáles AMGO. Minimização da erosão em função do tamanho e localização das áreas de floresta no contexto do programa “Conservador das Águas”. Rev Bras Cienc Solo. 2011;35:2157-66. https://doi.org/10.1590/S0100-06832011000600030