Water erosion modeling in a watershed under forest cultivation through the USLE model

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Abstract
The modeling of erosion processes integrated with a Geographic Information System (GIS) has been an important tool to assess erosion by water. The objective of this study was to determine the spatial distribution of water erosion in forest ecosystems and generate soil loss prediction maps according to different land use scenarios. The study was conducted in a watershed occupied by *Eucalyptus* cultivation located in Belo Oriente, in the Rio Doce river valley, Central-East region of Minas Gerais state, Brazil. For the spatial distribution modeling of soil loss for the watershed, the USLE model was applied coupled with Geographic Information System (GIS). The lowest soil loss, among the scenarios evaluated, was predicted for the land use of *Eucalyptus* with conservationist-practices, *Eucalyptus* with non-conservationist-practices, and native forest, indicating a strong influence of the vegetation cover, expressed by the USLE C-factor, in guaranteeing a good protection for the soil and conservationist use practice efficiency in controlling water erosion.

Key Words
Latosol (Oxisol), Cambisol (Inceptsol), tolerance of soil loss, sediment, canopy, Digital Elevation Model (DEM).

Introduction
Currently, forest plantations in Brazil covers 5.7 million hectares, generates 4.5 million direct and indirect jobs and contributes to more than 2% of GNP (Gross National Product) (Hoeflich and Tuoto 2008). Minas Gerais is the state with the highest planted eucalyptus forest area in Brazil. According to the report of the Minas Forestry Association (MFA), the annual planting of forests in the State increased five and a half times in one decade, from 35,789 hectares, in 1999, to 198,500 hectares in 2008 (Celulose Online 2009). Most of those plantations are concentrated in the areas of the Rio Doce river valley, Central-West, Northeast, Central/North and the Jequitinhonha/Mucuri valley (Minas Gerais 2008). The Rio Doce river valley, currently, is one of the most degraded areas in the state of Minas Gerais, due to water erosion.

According to the current market demands, in terms of sustainable production, erosion by water should be considered a priority, since it is the consequence of inappropriate land use. Soil is considered a non-renewable resource, and sediment is largely responsible for compromising the amount and quality of the water and silting the water bodies. As a form of aiding in the identification of areas with high and low susceptibility to water erosion and to understand the erosive mechanisms, as well as their causes and effects, water erosion modeling has been used. Erosion process modeling can be used as an environmental indicator of specific management zones and in the determination of conservation practices. The most used model throughout world is the Universal Soil Loss Equation-USLE (Wishmeier and Smith 1978), due to its simplicity. It is well known and studied, and it needs a relatively small quantity of information to make a prediction. With the advent of technology, many works integrating USLE factors with the Geographic Information System (GIS) have been developed with the aim to distribute spatially and predict soil losses for certain areas (Erdogan *et al.* 2007; Ozcan *et al.* 2008; Bahadur 2009; Beskow *et al.* 2009). The objective of this study was to determine the spatial distribution of water erosion in a forested watershed and generate soil loss prediction maps based on different land use scenarios, for the purpose of evaluating soil loss in case the current use (forest plantation) is changed.

Methods
The study was carried out in a watershed currently used as a *Eucalyptus* forest plantation, located in the municipal district of Belo Oriente (coordinates 19º13'12 S and 42º29'01 W), with an area of 21.22 km^2,

located in Rio Doce river valley, central-east region of the Minas Gerais state, Brazil. The climate of the area is Aw, tropical with a dry winter followed by a rainy summer, according to Köppen classification, with the average temperature varying between 22 and 27ºC, the maxim being 32ºC and the minimum 18ºC. The average annual precipitation ranges from 701 to 1,500 mm and average altitude is 300 m. The soils were classified as very loamy texture Dystrophic Red Yellow Latosol - LVAd (Oxisol), very loamy texture typical Dystrophic Red Latosol - LVd (Oxisol), and very loamy texture typical Dystrophic Tb Haplic Cambisol - CXbd (Inceptisol) (Cenibra 2001) (Figure 1). The acceptable tolerance of soil loss by water erosion in the area, is 7.17 t/ha/yr for LVAd (Pires 2004), 11.22 t/ha/yr in LVd (Silva *et al.* 2002) and 8.79 t/ha/yr (Silva 2009).

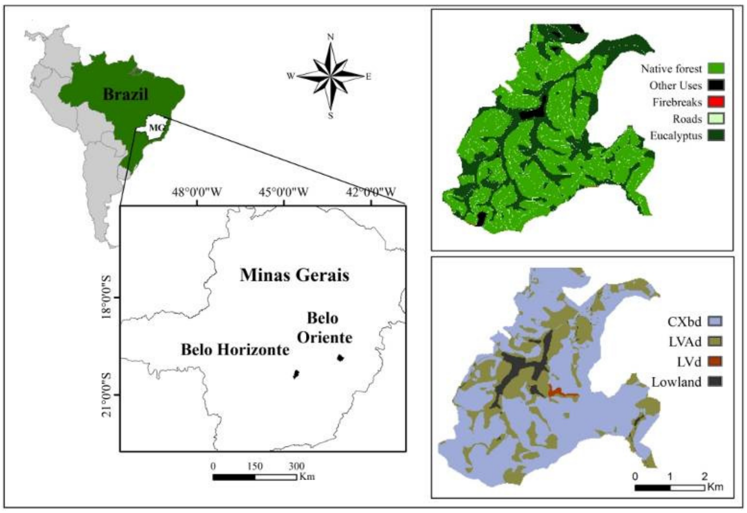

Figure 1. Localization of the municipality of Belo Oriente in Minas Gerais - Brazil, highlighting the soil map and the current land use of the watershed studied.

For the spatial distributed modeling of the soil losses in the watershed, the USLE was applied, which has the following expression (Wishmeier and Smith 1978):

$$A=R \times K \times LS \times C \times P \quad (1)$$

where A is the average annual soil loss in t/ha; R is average annual rainfall erosivity factor in MJ·mm/ha/h/yr; K represents the soil erodibility factor in t·h/MJ/mm; LS corresponds to slope length (dimensionless) and slope steepness (dimensionless) factors; C is the cover management factor (dimensionless); and P is the support practice factor (dimensionless). The software Arc GIS 9.2 was employed and coupled the USLE factors with the geographic information system and map making.

R factor: utilized a value of 10,745 MJ·mm/ha/h/yr according to Silva (2009).
K factor: the values of 0.0001 and 0.0002 t·h/MJ/mm were used for LVd and LVAd (Silva 2009) and 0.024 t·h/MJ/mm for CXbd (Silva 2003). The K factor map was determined based on the soil map.
LS factors: for the calculation of the LS factors, a Digital Elevation Model (DEM) was generated with 24-m resolution, and from it the slope map was obtained. The slope length factor (L) was obtained through the following equation (Wischmeier and Smith 1978):

$$L = (\lambda/22.13)^m \quad (2)$$

where: λ is the cell size; and m is slope length exponent determined by the following equations (Foster *et al.* 1977; McCool *et al.* 1989; Renard *et al.*1997).

$$m = \beta/ (1+\beta) \quad (3)$$

$$\beta = (\sin \theta/0.0896)/[3.0 \times (\sin \theta)^{0.8} + 0.56] \quad (4)$$

where: β is the ratio of rill to interrill erosion, and θ (degrees) is the slope drop angle.
The slope steepness factor (S) was determined according to Foster *et al*. (1977); McCool *et al*. (1989); and Renard *et al*. (1997).

$$S = 10.8 \times \sin \theta + 0.3, \text{ for slopes} < 9\% \quad (5)$$

$$S = 16.8 \times \sin \theta - 0.5, \text{ for slopes} \geq 9\% \quad (6)$$

C factor: the C factor values used were 0.016, 0.012 and 0.052 for the *Eucalyptus*, native forest and planted pasture, respectively (Silva 2009). The C factor map was obtained from the current land-use map.
P factor: P = 0.5 was used for the scenario with conservationist *Eucalyptus* and P = 1.0 for the other scenarios according to Bertoni and Lombardi Neto (2005). The analyzed scenarios were: soil loss maximum

potential (bare soil, BS), current land-use level planted *Eucalyptus* (conservationist system, LPE), up and downslope planted *Eucalyptus* (non-conservationist system, DPE), land-use with native forest (natural system, NF), and land-use with planted pasture (main land-use in the area, PP).

Results

The spatial distribution of the soil loss under the current land-use, soil loss maximum potential, and soil loss from different scenario are in Table 1 and Figure 2. When the extension occupied by each erosion class among the scenarios evaluated, it was noticed that 75, 57, 61, 46, and 39% of the area was below the average tolerable soil loss values in the area, for LPE, DPE, NF, BS, and PP, respectively. These results were high to those obtained by Weill and Sparovek (2008), which found about 30% of the Ceveiro watershed area, in Piracicaba, to be below the soil loss tolerance value.

Comparing the simulation results among the current land-use scenarios (conservationist and non-conservationist *Eucalyptus*) and the other scenarios (Table 1), it was verified that the conservationist *Eucalyptus*, non-conservationist *Eucalyptus*, and the native forest presented soil losses below 12 t/ha/yr in most of their area (> 60% of the area), confirming the capacity of the cultivation of forest species to protect the soil in a manner similar to the native forest, by promoting surface drainage reduction through the rain drops interception by the canopy as well as by the litter. The planted pasture presented large soil loss areas with over 12 t/ha/yr, about 50%, indicating that the substitution of the current land-use by planted pasture did not show sustainable for that area, agreeing with Machado *et al*. (2003), who found soil loss increases in simulations conducted in a watershed in Piracicaba, Brazil, when the native forest was replaced with pasture.

Table 1. Percentage of area occupied by erosion class.

Class	Soil Loss	LPE	DPE	NF	PP	BS
	t/ha	------------------	------------------	%------------------	------------------	------------------
1	0 - 1	37.6	35.3	35.7	34.7	18.5
2	1 - 3	13.0	5.9	8.3	3.7	6.0
3	3 - 6	12.4	9.3	9.4	4.1	7.4
4	6 - 9	11.9	6.5	7.5	3.6	6.9
5	9 - 12	12.0	5.9	7.5	4.6	5.0
6	> 12	13.3	37.2	31.7	49.4	56.1

LPE: land-use with level planted *Eucalyptus* (conservationist *Eucalyptus*); DPE: land-use with up and downslope planted *Eucalyptus* (non-conservationist *Eucalyptus*); NF: land-use with native forest; BS: bare soil (soil loss maximum potential); PP: land-use with planted pasture.

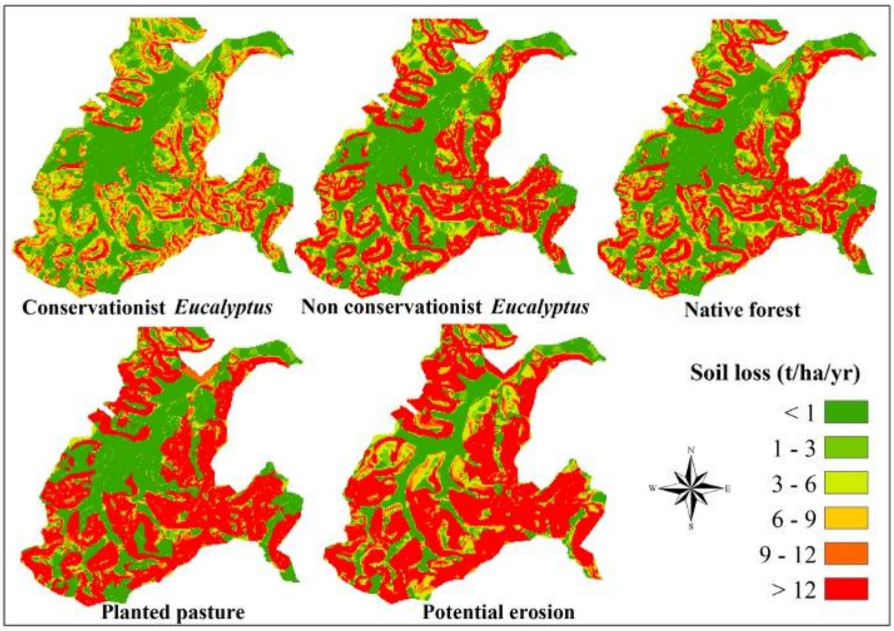

Figure 2. Soil loss in the different scenarios evaluated.

Conclusion

The least soil loss, among the appraised scenarios, occurred in the conservationist *Eucalyptus* land-use, native forest and non-conservationist *Eucalyptus*, indicating a strong influence of the vegetation cover, expressed by the USLE C-factor, in guaranteeing a good protection for the soil and conservationist use practice efficiency in controlling water erosion.

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