Flow hydraulic characteristics and interrill erosion susceptibility of natural and constructed Soils from Candiota coal mining Area, RS, Brazil

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Abstract
Soil particles detachment in interrill soil erosion is due to water raindrop impact on the soil surface. The transport of soil particles is by overland broad sheet flow enhanced by the flow turbulence caused by raindrop impact. The objectives of this study were to evaluate the flow hydraulic characteristics, to determine detachment rate and the interrill soil erodibility factor under simulated rainfall under laboratory conditions. Soil samples from natural and from 12 years old constructed soil were taken from the 20 cm topsoil Candiota coal mine, RS, Brazil. Laboratory simulated rainfall of 85 mm/h intensity was applied during 90 minutes on bare soil at interrill unit plot of 0.59 x 0.59 m settled on 0.09 m/m slope. The results showed that the flow hydraulic was laminar and subcritical. The interrill soil erodibility factor (Ki) for the 12 years constructed soil was 1.03 x 10^6 kg s/m^4 which was lower than for the natural soil (1.82 x10^6 kg s/m^4) due to the higher resistance of the constructed soil. The estimated Ki values were in the range of the soils used for the WEPP model (*Water Erosion Prediction Project*). Thus, they can be used to predict soil loss by erosion on hillslopes at the studied locations and soil types by applying this model.

Key Words
Interrill erosion, detachment rate, minesoils.

Introduction
Soil water erosion is a process of detachment, transport and deposition of soil particles caused by kinetic energy of the raindrops impact on soil surface and the associate overland flow (Ellison 1946). The process of water erosion occurs in two forms: interrill and rill erosion (Meyer *et al.* 1975). In interrill erosion soil particle detachment occurs by the water raindrop impact on the soil surface and soil particle transportation by overland broad sheet flow is enhanced by the flow turbulence (Foster *et al.* 1985). Soil water erosion is a major environment issue in coal mine reclamation areas. Environment reclamation at Candiota coal mine produces constructed soils composed of a surface layer formed by the natural soil A horizon, frequently mixed with B and C horizons, and a subsurface layer formed by a heterogeneous mixture of rock and saprolite materials. The soil erodibility is the reciprocal of its resistance to erosion, representing its susceptibility to erosion at different rates, due to physical, chemical and mineralogical parameters (Wischmeier and Mannering 1969; Foster 1982). In the models that separate the erosion in rills and interrills, the interrill soil erodibility represents the proportionality constant between soil detachment rate and the rainfall intensity. The objectives of this study were to evaluate the flow hydraulic characteristics, to determine detachment rate and the interrill soil erodibility under simulated rainfall at laboratory conditions for a natural and a 12 years constructed soil from Candiota coal mine, RS, Brazil.

Material and methods
The tests were carried out in the Soil Erosion Laboratory of Soils Department at Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, RS, Brazil. It used a 12 year old constructed soil and a natural soil (Paleudult) from the mine site, sampled in a coal mine located at Candiota, RS, Brazil. Soil samples were taken from the 20 cm topsoil, brought to the laboratory, air dried and passed through a 10 mm diameter opening sieve. An experiment was set up with an acrylic plot mounted on a 1.0 x 1.0 m metallic structure with useful area of 0.3481 m^2 (0.59 x 0.59 m), 0.10 m of depth and lateral edges 0.20 m of width. The plots were filled with a layer of 0.20 m crushed rock with 1.0 cm diameter, on which was placed a layer of 2.0 cm of sand and on top of these two layers it was placed a plastic screen with 1.0 mm opening. On this plastic screen was placed a 6.0 cm layer of air dried soil with bulk density of 1.3 g/cm^3. The soil in the plot was previously saturated for 24 hours. Simulated rainfall was applied at a water tension equivalent to 6

centimetres of water column and the experimental plot adjusted to a slope of 0.09 m/m. The rainfall was applied using a rainfall simulator (Souza 1985; Mayer and Harmon 1979), with nozzles type *Veejet* 80.150 (from *Spraying Systems Company, Chicago,USA*); internal diameter of 12.7 mm; settled to 3.1 m from the soil surface with an exit pressure of water of 41 kPa, checked with a manometer. The rainfalls were applied during 90 minutes, with average intensity of 85 mm/h.

A. Hydraulics characteristics of the flow surface

The flow discharge rate (Q), in m^3/s, was determined by measuring the volume of runoff collected in plastic pots. The flow unit discharge (q) in m^2/s was calculated by dividing the total discharge rate by the plot width. The surface flow velocity (m/s) was determined by taken the time for a dye cover a fixed distance between two points in the plot at 5 minutes intervals. The average flow velocity was determined by multiplying the surface velocity by a correction factor ($\alpha = 2/3$) (Farenhost and Bryan 1995; Katz *et al.* 1995). The flow depth (h) was determined according to Woolhiser and Liggett (1967) and Singh (1983), the Reynolds number (Re) according to Simons and Senturk (2002) and Froude (Fr) according to Chow (1959).

B. Determination of interrill erosion rates

The interrill soil detachment rate was determined by weighting the sediment collected during 1 minute in 1L plastic pots, at 3 minutes intervals throughout the time of the rainfall. After the weighting, it was added 5 mL potassium alum (50 g/L), for particles settling. After 24 hours, the excess of water was removed by suction and the pots with the sediment oven-dried at 50ºC until constant weight. The interrill soil detachment rate (Di), $kg/m^2/s$, was determined by the following relation:

$$D_i = \frac{Mss}{A\ D} \tag{1}$$

Mss = dry soil mass (kg); A = plot area (m^2); D = time of sampling (s).

The WEPP model (Flanagan and Nearinng 1995) consider that the interrill soil detachment rate at condition of bare soil, is given by:

$$D_i = K_i\ I^2\ S_f \tag{2}$$

D_i = interrill detachment rate ($kg/m^2/s$); K_i = interrill soil erodibility factor ($kg\ s/m^4$); I = rainfall intensity (m/s); S_f = soil slope factor. At the WEPP model (Liebenow *et al.*1990) the soil slope factor is adjusted by the equation:

$$S_f = 1{,}05 - 0{,}85 e^{4 sen\theta} \tag{3}$$

where θ represents the angle of slope (in degrees).

The interril soil detachment rate (Di) was determined at the experiment by an average of the last five measurements in each one of the four rainfall runs. Thus, with the known rainfall intensity and Sf factor adjusted for 0.09 m/m slope the interrill soil erodibility (Ki) factor may be determined by the following expression:

$$K_i = \frac{D_i}{I^2\ S_f} \tag{4}$$

K_i = interril fsoil erodibility factor ($kg\ s/m^4$); D_i = interrill detachment rate ($kg/m^2/s$); I = rainfall intensity (m/s); S_f = soil slope factor.

Results

The flow Reynolds number was 14.82 and Froude number 0.99 for the constructed soil and 14.03 and 0.62 for the natural soil (Table 1). Thus, these characterize a laminar and subcritical flow regime, as indicated by the values of Re < 500 e Fr < 1, respectively, typical of interrill erosion flow conditions. In Figure 1a and 1b it can be observed that the detachment rates presented a slight growing during the time of rainfall application, with tendency to become constant in last the 18 minutes, when they reached its maximum value. Thus, the average detachment rate in the last 18 minutes of rainfall was used for determination of interrill soil erodibility (Ki), with values of 2.62×10^{-4} $kg/m^2/s$ and 4.64×10^{-4} $kg/m^2/s$ for the constructed soil and natural soil, respectively, obtained as the average value of the last five determinations during the rainfall (Table 2). The average value of interrill soil erodibility (Ki) factor determined for the constructed soil was of 1.03×10^6 $kg\ s/m^4$, lower than the value for the natural soil, that was of 1.82×10^6 $kg\ s/m^4$ (Table 2). This may indicate that the constructed soil is more resistant to raindrop impact than the natural soil. One possible explanation is the type of structural units formed by the action of soil removal, disposal and reconstruction by heavy equipments that through compaction produced units that are very hard and resistant to the detachment by raindrop impact. The values of 1.03 x 10^6 and 1.82 x 10^6 kg s/m^4 determined for the interrill soil erodibility (Ki) factor for the constructed soil and natural soil, respectively, are within the range of values determined for soils that were used to develop the WEPP model (Alberts *et al.* 1995), between 0.5 and 12.10^6 kg s/m^4.

Table 1. Hydraulic characteristics of the interrill flow.

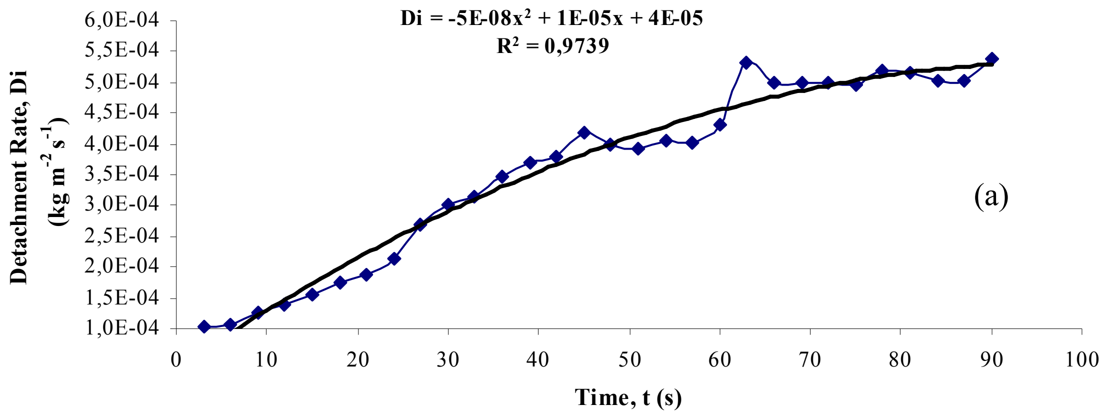
Soils	q	Vs	Vm	h	T	ν	Re	Fr
	m²/s	m/s	m/s	m	°C	m²/s	----adimensional-----	
CS 12 years	1,44E-05	0,076739	0,05116	0,000293	21,3	9,73E-07	14,82	0,99
Natural	1,32E-05	0,054928	0,036618	0,000372	22,75	9,43E-07	14,03	0,62

CS: constructed soil. q: net discharge by unit of width; Vs: surface velocity of the flow; Vm: average velocity of the flow; h: height sheet of the flow; T: temperature; **ν:** kinematics velocity; Re: Reynolds number; Fr: Froude number

Table 2. Detachment rate (Di) and interrill soil erodibility (Ki), Average of the four repetitions on rainfall with intensity of 85 mm/h(I =0,0000236 m/s) and slope of 0,09 m/m (Sf = 0,4560)

Soils	Di	Ki
	(kg/m^2/s)	(kg s/m^4)
CS 12 years	2,62 E– 04 b	1, 03 E + 06 b
Natural soil	4,64 E – 04 a	1,82 E + 06 a

CS: constructed soil. Followed values of same letters in the columns do not differentiate between itself for the test of Tukey to level of 5% of significance.



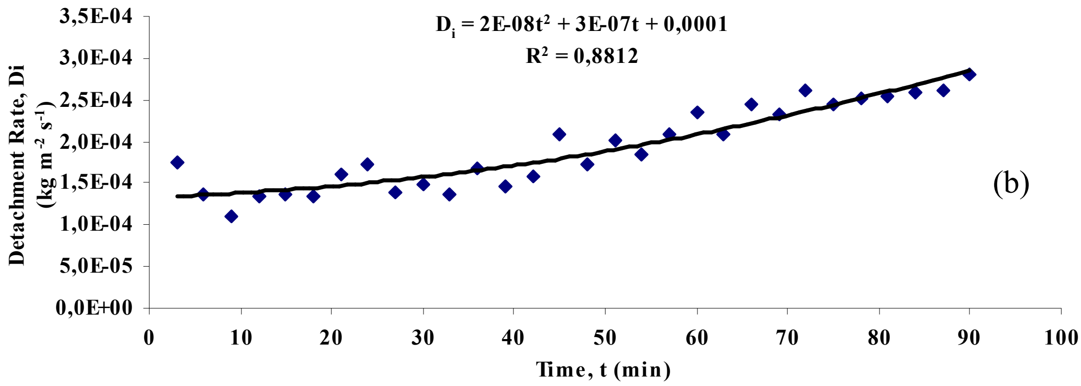


Figure 1. Interrill detachment rate of soil on simulated rainfall of 85 mm/h in slope of 0.09 m/m for: (a) natural soil; (b) constructed soil of 12 years old.

Conclusions

The flow hydraulic was laminar and subcritical for both soils studied, which are characteristic for interrill erosion conditions. The value of the interrill soil erodibility factor (Ki) determined for the constructed soil (1.03×10^6 kg s/m^4) was lower than the value obtained for the natural soil (1.82×10^6 kg s/m^4), values that are within the range for WEPP model (*Water Erosion Prediction Project*) prediction of soil loss erosion in hillslopes.

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