Effects of vegetation on erosion in technosols produced from coal waste

Daniel Campos Moro, Jéssica Weiler, Ivo André Homrich Schneider

Universidade Federal do Rio Grande do Sul - UFRGS, Departamento de Engenharia de Minas, Laboratório de Tecnologia Mineral e Ambiental, Porto Alegre – Rio Grande do Sul – Brasil, daniel.campos@ufrgs.br, jessica.weiler18@gmail.com, ivo.andre@ufrgs.br

Abstract

The aim of this study was to evaluate soil loss by water erosion considering different technosols configurations produced from fine and coarse coal waste and an agricultural soil. All substrates were amended with sewage sludge to obtain 3% organic matter. The study considered two precipitation levels and the presence, or not, of the *Medicago sativa* (alfalfa) and grass. Calculations were carried using the Revised Universal Soil Loss Equation. In terms of erosion control, the best configuration was attained with the mixture of coarse and fine waste. The presence of vegetation reduces in almost 100 times soil loss due rainfall.

Keywords: Mining Waste, Technosols, PlantGrowth, Soil Erosion, Rehabilitation

Introduction

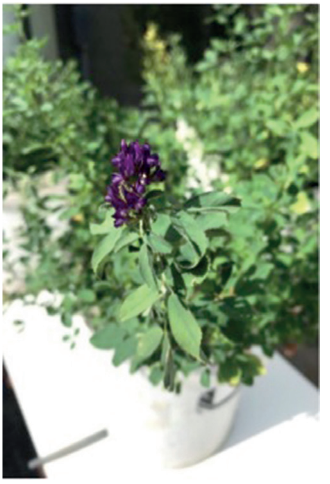
Mining sites should be properly managed. Environmental control is essential in the contemporaneous mining as well as in environmental liabilities eventually left by past mineral exploration activities. In this multivariable system, the control of topsoil erosion is one of the important issues to be considered (Yellishetty *et al*, 2013; Zhang *et al*, 2015).

In coal processing plants, coarse and/ or fine wastes are produced from parallel circuits (Leonard, 1991; Riazi and Grupta, 2015). Among the main impacts of mining waste disposal are changes in the physical and chemical conditions of the soil, which hinders plant growth (Ghose, 2005; Daniels and Stewart, 2010; Sheoran *et al*., 2010; Kossoff *et al*, 2014). The most common strategy to land rehabilitation is to cover coal waste with the native topsoil removed and stored from the beginning of the mining activity and/or with natural soil from borrow areas (Daniels and Zipper, 2010).

The presence of vegetation is very important to prevent particles transportation by wind or water (Ghose, 2005; Brotons *et al*, 2010; Sheoran *et al*., 2010; Zhang *et al*., 2013; Ghose, 2005; Zhang *et al*., 2015). Soil erosion can generate several negative impacts, including the transport of sediments to water bodies. Thus, it is important to consider strategies of progressive rehabilitation of coal waste deposits, such as the establishment of technosols - artificial soils derived from anthropic materials – which can speed up the revegetation. Recent studies have demonstrated success in plant growth of substrates produced from coal mine wastes amended with organic and alkaline materials (Firpo *et al*., 2015, 2020; Weiler *et al*., 2018, 2020).

The aim of this study was to evaluate soil loss by water erosion considering different technosols configurations produced from fine and coarse coal waste and an agricultural soil. The study also considered the effect of the cultivar Medicago sativa (alfalfa) and grass on the erosion process.

Preparation of technsols



Alfalfa and grass growth

Root system

***Figure 1** Alfalfa and grass growth in technosol experiment.*

Methodology

The study is part of a current experiment in Brazil (started in Dec. 2018), at the Federal University of Rio Grande do Sul. A mixture of mineral (fine and coarse coal waste) and organic (sewage sludge) material to produce technosols was performed in 25 L vessels (Figure 1). The mineral matrix was obtained from the Moatize Mine in Mozambique, one of the largest coal deposits in Africa. In relation to generation of coarse and fine wastes, the beneficiation of coarse ROM particles is performed by dense medium cyclones (1 mm < d < 50 mm) while the fine ROM particles, by spirals or elutriation (fraction 0.25 < d < 1 mm) and by flotation (fractions d < 0.25 mm). The sludge came from a municipal sewage treatment plant.

Fine and coarse coal waste were analyzed by granular and mineral properties. Granular properties of samples were evaluated by particle size distribution, particle density, bulk density, and porosity. Particle size distribution was performed using a Tyler standard screen series. Particle density was determined gravimetrically by pycnometry. Bulk density (or apparent density) and porosity, which were carried out following ASTM D167 (ASTM, 2012a). Mineralogical analysis was carried out by X-ray diffraction (XRD) in a Siemens (Bruker AXS, United States) X-ray diffractometer.

Six technosols using different layer configurations of materials were evaluated, all of them with sewage sludge to obtain 3% organic matter: 1. Fine coal waste (FCW); 2. FCW + Coarse coal waste (CCW) – composing two seams; 3. FCW + CCW – as a mixture; 4. Agricultural soil (AS) + FCW + CCW – composing three seams; 5. AS + mixture of FCW + CCW – composing two seams; 6. AS + FCW + CCW – as a mixture. The last one, numbered as 7 and used as control, was composed just by agricultural soil. The technosols layers are presented in Figure 2. Plant growth have been simulated with *Medicago sativa*, one of the cultivars that present successful growth is such tecnosols (Weiler *et al*, 2020).

The Revised Universal Soil Loss Equation (RUSLE) was used to estimate to estimate the annual soil loss from different soil configurations. The formula of the RUSLE is as follows (equation 1):

$$A = R.K.(L.S).(C.P) \qquad (1)$$

where A is the predicted soil loss on the average unit area (t ha^{-1} y^{-1}); R is the rainfall erosivity factor (MJ mm ha^{-1} h^{-1} y^{-1}); K is the soil erodibility factor (dimensionless); LS is the terrain factor – surface length and slope (dimensionless); C is the cover management factor (dimensionless); and P is the conservation practice factor (dimensionless).

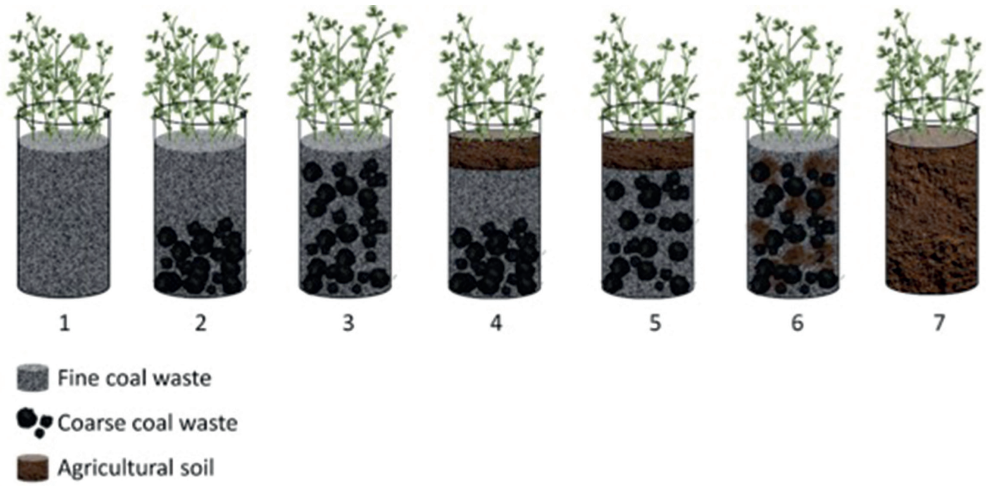


Figure 2 *Technosols produced with fine and coarse coal waste and agricultural soil in different layers.*

The parameters were adapted according to the geographic region of the coal wastes (Tete Province, Mozambique). It was considered a trapezoidal shape common format of the modules used for the disposal of mineral tailings with a surface inclination of 3°. To calculate the erosivity factor (R), the annual rainfall values of the studied region were considered, with minimum values of 532 mm year^{-1} and maximum values of 1028 mm year^{-1}, according to equation 2 (Roose, 1996):

$$R = a.0.8+0,05 \quad (2)$$

where a (mm y^{-1}) is the annual rainfall.

The soil erodibility factor (K) was defined from the EPIC-K equation, where it is necessary to know the organic composition of the soil and its particle size distribution. The formula is (equation 3): (3)
where: SAN, SIL and CLA is % of sand, silt and clay in the particle composition, respectively; C' is % of organic carbon in the soil;

$SN_1 = 1 - \frac{SAN}{100}$.

The topographic factors, referring to the length and slope of the studied surface, were obtained from the adaptation of the equations provided by the LS-TOOL Software (Zhang *et al.*, 2013), described below:

$$L = \left(\frac{\lambda}{22.13}\right)^m \quad (4)$$

$$m = \frac{\beta}{(1+\beta)} \quad (5)$$

$$\beta = \frac{sen\theta}{[3\times(sen\theta)^{0.8}+0.56]} \quad (6)$$

$$S = 10.8\times sen\theta + 0.03 \text{ se } \theta < 9\% \quad (7)$$

$$S = 16.8\times sen\theta - 0.5 \text{ se } \theta \geq 9\% \quad (8)$$

where: λ = surface length (m); m = exponent of length-slope variation; β = declivity factor; θ = surface inclination. Based on McCool *et al.* (1989)

The conservation practices factor (P) was considered 1.0, referring to the hillside vegetation management. This is due to the size of the waste disposal modules, which are not long enough to carry out practices such as contour lines and terracing, which would reduce the P factor to 0.5 and 0.1, respectively (Carvalho, 1994). Finally, the soil use and management factor (C) refers to the type of planting established on the analysis surface, considering Alfalfa and grass scenarios which correspond a C factor of 0,0134 (Schmidt *et al.*, 2017).

$$K = \left(0.2 + 0.3e^{\left[-0.0256SAN\left(1-\frac{SIL}{100}\right)\right]}\right) \times \left(\frac{SIL}{CLA+SIL}\right)^{0.3} \times \left[1 - \frac{0.25C\prime}{C'+e^{(3.72-2.95C)}}\right] \times \left[1 - \frac{0.7SN_1}{SN_1+e^{(22.9SN_1-5.51)}}\right]$$

Equation 3

Table 1 Crystalline components and particle analysis of the components of technosols.

	Fine waste	Coarse waste	Agricultural Soil
Crystalline components			
Major	Quartz	Quartz	Quartz, kaolinite
Minor	Calcite, hematite	Calcite, hematite	Hematite
Particle analysis			
Sand (%)	96.6	8.95	41.75
Silt (%)	3.4	0.22	35.55
Clay (%)	0	0	22.7
Particle size (mm)	0.1 – 1.0	0.5 – 50.0	< 2.0
Density (g cm-3)	1.79	2.21	1,55
Apparent density (g cm-3)	1.09	1.18	1,05
Porosity (%)	46.5	39.5	10

Results

Properties of the materials used to construct the technosols are depicted in Table 1. Regarding the crystalline composition, coal wastes are mainly composed of quartz, calcite and hematite while the agricultural soil by kaolinite and quartz. The particle size distribution varies from 0.1 to 1 mm for fine waste, from 0.5 to 50 mm coarse waste and less than 2 mm for agricultural soil. This assessment was carried out in a previous study by Weiler *et al*. (2020).

The results of soil loss using the RUSLE equation for the technosols configurations, for two precipitation conditions (532 and 1078 mm y^{-1}) and with alfalfa and grass planting, are shown in Table 2. Soil 3 has the lowest soil loss compared to the others, with a loss of 0.13 t ha^{-1} y^{-1} considering a precipitation of 532 mm y^{-1} and 0.27 t ha^{-1} y-1 considering a precipitation of 1078 mm y^{-1}. Soils 4, 5 and 7, which contain agricultural soil on the surface, had higher soil loss. This is due to the fact that the particle size of the agricultural soil is lower than that of the tailings, reducing the soil erodibility factor (K) in the RUSLE equation.

The results presented in Figure 3 were obtained considering the best technosol configuration and the agricultural soil with and without vegetation (alfalfa and grass). They clearly indicate the importance of the vegetation to the erosion control. For a precipitation of 532 mm y^{-1}, the soil loss would increase from 0.13 to 10.03 t ha^{-1} y^{-1} for Technosol 3 and from 0.17 to 13.02 t ha^{-1} y^{-1} for agricultural soil. So, provide a proper condition for plant growth is an essential step in the process of ecological restoration in mining areas.

Table 2 Soil loss in technsols with a vegetation coverage compose by alfalfa and grass considering two precipitation levels and seven soil configurations.

Precipitation mm y^{-1}	Soil Configuration	Soil loss t ha^{-1} y^{-1}
532	1	0.16
	2	0.16
	3	0.13
	4	0.17
	5	0.17
	6	0.17
	7	0.17
1078	1	0.31
	2	0.31
	3	0.27
	4	0.35
	5	0.34
	6	0.34
	7	0.35

Results attained in this work are consistent with some others encountered in the literature. Yellishetty *et al*. (2013) also estimated the soil erosion from mine waste rock dumps using the RUSLE model, finding values between 5 and 25 t ha^{-1} y^{-1} dependent on the slope angle and slope length. These values are similar to those found for soils without plants presented in this work (10,03 and 13,02 t ha^{-1} y^{-1}). Zhang *et al*. (2015) investigated the effects of vegetation on erosion with a field experiment in coal-mine dumps: considering the local rainy season (331 mm), the soil loss was approximately 5 t ha^{-1} for a soil with vegetation and 25 ha^{-1} for soil without vegetation. The values found

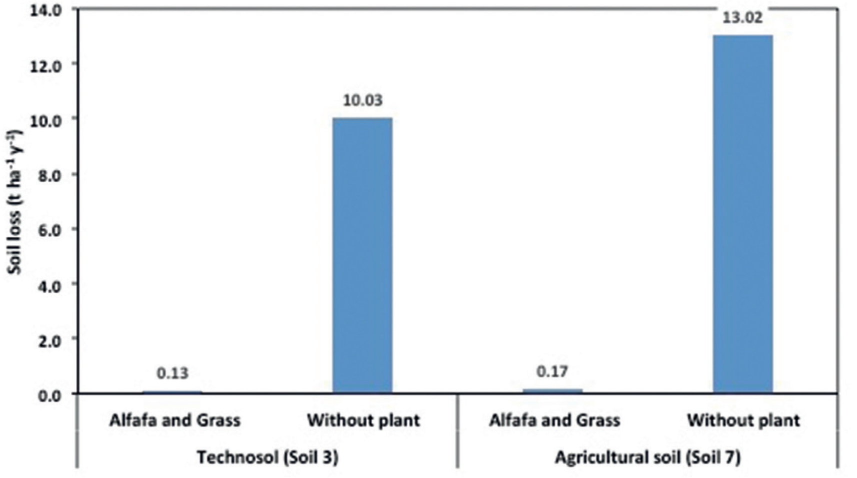


Figure 3 *Soil loss on a technosol and agricultural soil with and without plant coverage considering an annual precipitation of 532 mm.*

considering the use of alfalfa in the present study were lower, but both studies present a great difference in terms of erosion between the soil with and without vegetation. These results confirm that vegetation is fundamental in the conservation of water and soil as well as in the ecology restoration in mined areas.

Conclusion

This study confirms that technosols produced from coal waste can be a successful strategy to the rehabilitation process, allowing plant growth and erosion control. Best configuration for erosion control was attained with the mixture of fine and coarse coal waste in one single layer. The presence of vegetation reduces in almost 100 times soil loss due rainfall. Considering the calculations, soil loss in Moçambique coal deposits the order of 10 t ha^{-1} y^{-1} can be reduced to 0.1 t ha^{-1} y^{-1} as long as is suitable conditions for plant growth. Field observation should be carry out to confirm these results.

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