Comissão 3.5 - Poluição, remediação do solo e recuperação de áreas degradadas

PERENNIAL GRASSES FOR RECOVERY OF THE AGGREGATION CAPACITY OF A RECONSTRUCTED SOIL IN A COAL MINING AREA IN SOUTHERN BRAZIL[1]

Lizete Stumpf[2], Eloy Antonio Pauletto[3], Flavia Fontana Fernandes[4], Luis Eduardo Akiyoshi Sanches Suzuki[5], Tiago Stumpf da Silva[6], Luiz Fernando Spinelli Pinto[3] & Claudia Liane Rodrigues de Lima[4]

SUMMARY

The construction of a soil after surface coal mining involves heavy machinery traffic during the topographic regeneration of the area, resulting in compaction of the relocated soil layers. This leads to problems with water infiltration and redistribution along the new profile, causing water erosion and consequently hampering the revegetation of the reconstructed soil. The planting of species useful in the process of soil decompaction is a promising strategy for the recovery of the soil structural quality. This study investigated the influence of different perennial grasses on the recovery of reconstructed soil aggregation in a coal mining area of the Companhia Riograndense de Mineração, located in Candiota-RS, which were planted in September/October 2007. The treatments consisted of planting: T1- *Cynodon dactylon* cv vaquero; T2 - *Urochloa brizantha*; T3 - *Panicum maximun*; T4 - *Urochloa humidicola;* T5 - *Hemarthria altissima*; T6 - *Cynodon dactylon* cv tifton 85. Bare reconstructed soil, adjacent to the experimental area, was used as control treatment (T7) and natural soil adjacent to the mining area covered with native vegetation was used as reference area (T8). Disturbed and undisturbed soil samples were collected in October/2009 (layers 0.00-0.05 and 0.10-0.15 m) to determine the percentage of macro- and microaggregates, mean weight diameter (MWD) of aggregates, organic matter content, bulk density, and macro- and microporosity. The lower values of macroaggregates and MWD in the surface than in the

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[2] Doctoral student, PPGA/FAEM/UFPel. Rua Campus Universitário Capão do Leão, s/n. CEP 96900-010 Capão do Leão (RS). E-mail: zete.stumpf@gmail.com

[3] Associate professor, Soil Science Department, FAEM/UFPel. E-mail: pauletto_sul@yahoo.com.br, lfspin@ufpel.tche.br

[4] Adjunct professor, Soil Science Department, FAEM/UFPel. E-mail: f_flavia_fernandes@yahoo.com, brclrlima@yahoo.com.br

[5] Adjunct professor, Centro de Desenvolvimento Tecnológico, UFPel. Rua Gomes Carneiro, 01, Campus Porto. CEP 96001-970 Pelotas (RS). E-mail: dusuzuki@gmail.com

[6] Undergraduate student, FAEM/UFPel. E-mail: tiago.stumpf@hotmail.com

subsurface layer of the reconstructed soil resulted from the high degree of compaction caused by the traffic of heavy machinery on the clay material. After 24 months, all experimental grass treatments showed improvements in soil aggregation compared to the bare reconstructed soil (control), mainly in the 0.00-0.05 m layer, particularly in the two *Urochloa* treatments (T2 and T4) and *Hemarthria altissima* (T5). However, the great differences between the treatments with grasses and natural soil (reference) indicate that the recovery of the pre-mining soil structure could take decades.

Index terms: soil construction, macroaggregates, microaggregates, mean weight diameter, cover plants.

RESUMO: *RECUPERAÇÃO DA AGREGAÇÃO DE UM SOLO CONSTRUÍDO EM ÁREA DE MINERAÇÃO DE CARVÃO NO SUL DO BRASIL COM O USO DE GRAMÍNEAS PERENES*

A construção do solo após a mineração de carvão a céu aberto envolve intenso tráfego de máquinas durante a recomposição topográfica da área, acarretando a compactação das suas camadas repostas, o que gera problemas de infiltração e redistribuição da água ao longo do novo perfil, facilita a erosão hídrica e, consequentemente, dificulta a revegetação do solo construído. O uso de plantas que auxiliam no processo de descompactação do solo constitui-se em importante estratégia na recuperação da qualidade estrutural do solo. Este trabalho analisou a influência de diferentes gramíneas perenes na recuperação da agregação de um solo construído na área de mineração de carvão da Companhia Riograndense de Mineração, localizado em Candiota, RS, implantadas em setembro/outubro de 2007. Os tratamentos estudados foram: T1 - Cynodon dactylon *cv vaquero; T2 -* Urochloa brizantha*; T3 -* Panicum maximun*; T4 -* Urochloa humidicola*; T5 -* Hemarthria altissima*; e T6 -* Cynodon dactylon *cv tifton 85. Como testemunha, foi utilizada uma área com solo construído sem plantas de cobertura, adjacente à área experimental, denominado T7; e, como referência, uma área com solo natural à frente da mineração, denominada T8. Amostras de solo não preservadas e preservadas foram coletadas em outubro/2009, nas camadas de 0,00-0,05 e 0,10-0,15 m, determinando-se porcentagem de macro e microagregados, diâmetro médio ponderado de agregados (DMP), teor de matéria orgânica, densidade do solo, macro e microporosidade. Os menores valores de macroagregados e do DMP da camada de 0,00-0,05 m do solo construído em relação à camada subsuperficial resultaram do alto grau de compactação dessa, ocasionada pelo tráfego de máquinas pesadas sobre o material argiloso. Após 24 meses de condução do experimento, todos os tratamentos apresentaram melhorias na agregação do solo, quando comparados ao solo construído sem plantas de cobertura (testemunha), principalmente na camada de 0,00-0,05 m, com destaque para as duas espécies de* Urochloa *(T2 e T4) e a* Hermathria altissima *(T5). No entanto, as grandes diferenças entre os tratamentos com gramíneas e o solo natural (referência) sugeriram um tempo muito longo para a recuperação das condições estruturais do solo anteriores à mineração.*

Termos de indexação: construção do solo, macroagregados, microagregados, diâmetro médio ponderado, plantas de cobertura.

INTRODUCTION

To date, most studies addressing the recovery of soil reconstructed after opencast mining focused on the reposition of soil covering the mine pits filled with tailings, after the topographic remodeling of the area (Arranz-González, 2011). However, the repeated movement of heavy equipment during transport and replenishment overdriving the soil layers causes compaction of the structural units, with significant changes in the soil structure (Chinn & Pillai, 2008), forming aggregates with a high mean weight diameter but inadequate pore size distribution within the aggregates (Bertol et al., 2004), which may restrict the establishment of vegetation for long periods.

The main change induced by surface mining is the physical degradation, because the original soil profile is completely overturned, with completely different characteristics after soil reconstruction, in which the materials are destructured, mixed and exposed to weathering for long periods.

In Candiota, Rio Grande do Sul, the region with the largest coal deposits of the country, open pit mines are installed by removing the soil horizons (horizons A, B, or C) and geological layers (sandstones, shales and siltstones), followed by mineral coal extraction. During the topographic reconstruction of the area, the unworkable material (rocks and unexploited coal seams) is filled back into the open pits and covered with a soil layer, often rather thin, taken from the surroundings of the coal mine. The whole process results in a high compaction level of the new profile, characterized by the presence of aggregates of larger size in the subsurface layer, high bulk density, low total porosity and a disproportional relationship between macro- and micropores (Nunes, 2002), probably resulting from excessive heavy machinery traffic during the reconstruction of the soil, often at inadequate soil moisture levels.

However, adequate soil and cover crops can be useful in the recovery of areas degraded by coal mining. Several studies have shown the capacity of different cover crops for revegetation and consequently improve the soil conditions of degraded areas (Silva et al., 2006; Lunardi Neto et al., 2008; Silva & Corrêa, 2010; Longo et al., 2011; Barros et al., 2012). However, further research is needed to identify the best-suited plant species to improve the soil physical quality under specific soil and climate conditions (Andrade et al., 2009).

A possibility of minimizing compaction (Lima et al., 2012) is to plant cover crops that produce large amounts of roots and crop residues (Cardoso et al., 2003), since the roots can influence soil stabilization directly or indirectly by physical protection, and by exudates and their decomposition (Alvarenga et al. 1995).

According to Cardoso et al. (2003), cover crops that produce large amounts of dry matter, covering soil more quickly than others, and with a deep root system with a large volume, are able to generate transversal biopores along the profile, minimizing the effects of soil compaction. These biopores can improve the connectivity between the surface and subsurface layers, favoring the vertical water flow and gas diffusion, apart from serving as pathways for root penetration of subsequent crops (Chioderoli et. al., 2012).

Perennial grasses can be used to recover the soil structure in degraded areas, mainly due to the high root density, periodic renewals of the root system and uniform distribution of root exudates in the soil (Silva & Mielniczuck, 1997).

Former mining areas form degraded ecosystems, since along with the vegetation, the biotic regeneration capacity as well as the seed bank and fertile soil layer were eliminated. Consequently, the soil may fail to return to its previous state or recovery may occur at an extremely slow pace (Alves & Souza, 2011). Therefore, measures are required to maximize the viability of the new ecosystem in the long term (Shrestha & Lal, 2011) so that the reconstructed soil reassumes functions in the environment.

Few studies have addressed the reclamation of degraded areas after open coal mining, especially in Rio Grande do Sul, where 90.6 % of the national coal reserves are concentrated (DNPM, 2010). In this context, the purpose of this study was to evaluate the effect of six cover crops on aggregation of a reconstructed soil in a coal mining area in southern Brazil.

MATERIAL AND METHODS

Study area

The study was conducted in a coal mining area that belongs to the mining company Companhia Riograndense de Mineração (CRM), located in the municipality of Candiota, Rio Grande do Sul, Brazil (31° 33' 55" S, 53° 43' 30" W).

The layer of replaced soil in the experimental area had been taken from a B horizon of the natural soil of the pre-mined area, a Rhodic Lixisol, as indicated by the reddish color (2.5YR 3.5/6), with low organic matter content and clay texture in the 0.00-0.15 m layer (Table 1).

The soil was reconstructed in early 2003. Before the experiment, the area had been extremely compacted by the repeated movement of machinery during soil reconstruction (trucks loaded with approximately 20 Mg of humus and a crawler tractor, model D8T Caterpillar ®, weight 38 Mg, power 259 KW, track length 3.20 m track width 0.56 m, track-soil contact area 3.6 m^2). To minimize compaction, the reconstructed soil was chiseled with a motor grader to a depth of approximately 0.15 m, followed by liming (10.4 Mg ha^{-1} with limestone TRNP = 100 %) and fertilization (900 kg ha^{-1} N-P-K fertilizer at 5-20-20), as indicated by the results of soil analysis.

The experiment was installed between September/October 2007 in 20-m^2 plots, in a randomized block design with four replications. The tested species were: T1 - *Cynodon dactylon* cv vaquero; T2 - *Urochloa brizantha*; T3 - *Panicum maximun*; T4 - *Urochloa humidicola;* T5 - *Hemarthria altissima*; T6 - *Cynodon dactylon* cv tifton 85. Bare reconstructed soil, adjacent to the experimental area, was used as control treatment -T7, and natural soil adjacent to the mining area, covered with native vegetation, was used as reference area -T8.

Soil sampling

In October 2009, 56 disturbed samples were collected from the layers 0.00-0.05 and 0.10-0.15 m (four blocks x seven treatments x one rep per plot x two soil layers) to determine the distribution of water stable aggregates in different size classes, the average diameter of stable aggregates in water and organic matter contents of the soil.

Table 1. Chemical and physical properties of the surface layer of the reconstructed soil prior to the experiment

pH (H_2O)	Organic matter	Ca	Mg	Al	Potential acidity	CEC	K	Na	P	Sand	Silt	Clay
	%	cmol$_c$ kg^{-1}					mg kg^{-1}			g kg^{-1}		
5.60	1.15	2.65	2.11	1.28	3.80	8.69	27.66	11.64	1.23	315	209	476

We also collected 112 undisturbed samples (four blocks x seven treatments x two replications per plot x two layers) with steel cylinders (height 0.030 m, diameter 0.0485 m) to determine bulk density (Blake & Hartge, 1986), total porosity, and macro- and microporosity (Embrapa, 2011).

Analysis of soil physical and organic matter properties

The undisturbed samples were sieved (9.5 mm mesh), by the wet-sieving method described by Kemper & Rosenau (1986) and modified by Palmeira et al. (1999). Approximately 250 g air-dried sample material was separated into four equal parts, one of which was used for moisture content determination and the others as replications to determine the aggregate-size distribution using a wet-sieving apparatus (Yoder, 1936). Wet sieving is carried out in a cylindrical container containing three sets of sieves (mesh diameter 2.0, 1.0, 0.25 and 0.105 mm), so that each field sample is analyzed in triplicate. In each sieve set, the aggregate sample was placed on the largest mesh sieve lined with filter paper to retain the soil until saturation by capillarity for 10 min. After saturation, the paper was removed with a low pressure water jet and then the vertical movement of the oscillation device was activated (30 oscillations per min for 15 min). Finally, the soil retained on each sieve was transferred into cans by weak water jets directed towards the bottom of the sieve and then oven-dried and weighed.

The ranges of aggregate classes were: C1: 9.52-4.76 mm; C2: 4.76-2.0 mm; C3: 2.00-1.00 mm; C4: 1.00-0.25 mm; C5: 0.25-0.105 mm and C6: < 0.105 mm. From these classes, the macroaggregates were separated into clusters, i.e., aggregates > 0.25 mm and microaggregates, i.e., aggregates < 0.25 mm, according to Tisdall & Oades (1982).

The soil carbon content was determined in sieved samples (2 mm) by the Walkley-Black combustion method, as described by Tedesco et al. (1995). The amount of organic matter (OM) in the samples was calculated by the following equation: % OM = % C x 1.724.

The undisturbed samples were water-saturated by capillarity for 24 h and then placed on a tension table, where they were equilibrated at a voltage of 6 kPa to determine macroporosity. After equilibration, the samples were oven-dried at 105 °C to constant weight to determine bulk density and microporosity.

Data analysis

The data were subjected to analysis of variance ($p<0.05$) and in case of significant differences, the means of treatments T1 to T6 were compared by the Tukey test ($p<0.05$). Analyses were performed using SAS statistical software (SAS, 1985). Since the control treatment T7 (bare reconstructed soil) and the reference treatment T8 (natural soil adjacent to the mining area) were not included in the experimental design, the data of these treatments were not subjected to statistical procedures in the comparison with the other treatments.

RESULTS AND DISCUSSION

After 24 months, the grass treatments (T1 to T6) contained a lower percentage of macroaggregates and lower values of mean weight diameter (MWD) in the 0.00-0.05 than in the 0.10-0.15 m layer (Table 2). This initially unexpected result can be explained by the high compaction degree of the underlying layer, arising from the heavy traffic of machines during the topographic reconstruction of the mined area. Voorhees (1983) observed that a soil under traffic had aggregates with mean geometric diameter twice as great as that of traffic-free soil. Bergamin et al. (2010) reported an increase in MWD with increasing number of tractor passes on a clay soil (644 g kg^{-1}), and explained this result by a probable mechanical aggregation caused by the stress effect under high soil moisture. As stated by Conte et al. (2011), compacted soils can have high aggregate stability in water, however, the relationship between the distribution of micropores, macropores and total porosity are altered, hindering the root development of the cover crops.

In the field, a laminar structure was observed in the 0.10-0.15 m layer, indicating a high degree of compaction. According to Brady & Weil (2008), clay soils under heavy machinery traffic may have a laminar structure. Sencindiver & Ammons (2000) also found a laminar structure in some mined soils, attributing this to the compaction exerted by the vehicles. In this way, the 0.10-0.15 m layer of the studied reconstructed soil typically has physical conditions dominated by features related to the mining operations and soil construction. According to McSweeney & Jansen (1984) and Akala & Lal (2001), the soil used for the restoration of the mined area can be relocated to its destiny at varying degrees of disaggregation or compaction, depending on the moisture content, nature of the material and organic matter loss.

The physical degradation due to soil compaction leads to a reduction in the pore volume and, to some extent, to an increase in the proportion of fine pores as a result of the decrease in the proportion of larger pores (Baumgartl & Horn, 1991). The greater compaction in the 0.10-0.15 m than the 0.00-0.05 m layer can be confirmed by the much higher values of bulk density (BD) than 1.40 Mg m^{-3} and macroporosity values (Ma) well below 0.10 m^3 m^{-3} (Table 2), considered critical for an appropriate plant development (Reichert et al., 2007; Tormena et al., 1998).

The lower BD in the surface layer of mined soils may be the result of biological activity, incorporation of organic matter, root penetration and wetting and drying cycles (Sencindiver & Ammons, 2000). The same factors are probably responsible for the lower percentage of macroaggregates and MWD in the 0.00-0.05 m layer in relation to the underlying layer. According to Harris et al. (1966), the pressure exerted by root growth was associated with aggregate formation and breakdown in the soil, i.e., if on the one hand root penetration can cause the separation of the larger aggregates, on the other hand, disaggregated particles can be trapped and compressed in aggregates by the network of growing roots. The roots increase the effects of wetting and drying cycles in soil (Angers & Caron, 1998) in the breakdown of aggregates, mainly in clay soils, due to the intense water uptake through the roots (Ball et al. 2005).

In this context, significant differences were observed between the cover crops for the percentage of macroaggregates in the 0.00-0.05 m layer, especially in T4, T5 and T2 with highest values (77.08, 75.51 and 75.26 %, respectively), and for the variable MWD, where treatment T2 differed from T1 and T3, with the highest value (2.00 mm) (Table 2).

Hemarthria altissima (T5) was particularly effective at recovering degraded soil aggregates, due to the high growth speed and greater potential of biomass input over longer periods than other grasses (Santos, 2009). The *Urochloas* (T2 and T4) produce a considerable quantity, quality and distribution of root biomass (Crusciol et al., 2010) and have a capacity of decompacting soil (Silva et al., 2006; Calonego et. al., 2011).

For Paladini & Mielniczuk (1991), larger diameter aggregates tend to have a positive correlation with organic matter (OM), or as the content of organic matter increases, an increase in the cluster stability is noticed. However, this relationship was not observed in the case of the reconstructed soil studied, because the higher OM content in T3, T4 and T5 was not reflected in higher MWD in the 0.00-0.05 m layer (Table 2), where these two variables were not significantly correlated (r = 0.35). Therefore, to date the OM content was not identified as a relevant factor in the aggregation of reconstructed soil, probably due to the low values found so far. On the other hand, the root systems may be decisive for the results of MWD and macroagregation in the surface layer of reconstructed soil, once extended fibrous roots generally induce high aggregation levels (Harris et al. 1966). Lunardi Neto et al. (2008) reported that *Urochloa brizanta* improved MWD of a reconstructed soil after four years, attributing this to the fasciculate root system and residues of the plant shoots left on the ground. Muller et al. (2001) observed that cover crops tend to concentrate roots near the surface when the subsurface soil layer is compacted.

In all cases, the potential of cover crops to recover reconstructed soil is evident when the results of the grass treatments are compared to the properties of the bare reconstructed soil (T7). In agricultural soil, Vezzani & Mielniczuk (2011) observed that after 17 years of cultivation of perennial grasses with a dense root system, the macroaggregate proportion was recovered. Wick et al. (2008) compared reconstructed soil with grasses after 16 years to soil with grasses after 5 and 10 years and observed higher macroaggregate percentages in the former.

Numerically, however, the aggregation data were closer to the control (T7) than the natural soil (T8) used as reference. It was observed that the percentages of macroaggregates and MWD were higher (7.1-17.7 and 60-122.2 %, respectively) in all treatments (T1 to T6) than in T7, showing a positive action of the vegetation cover on aggregation in the surface layer of reconstructed soil (Table 2). Moreover, although the treatments did not differ from each other for the variables BD, TP and Ma, there were differences for T7, i.e., in the treatments T1 to T6 the BD was lower (3.9 to 9.7 %), and TP higher (7.1 to 11.9 %) and Ma higher (33.3 to 66.6 %) than in bare reconstructed soil (Table 2).

The importance of vegetation in the recovery of degraded soils becomes more evident when the differences in the percentage of microaggregates and OM content are observed. That is, the percentage of microaggregates in the 0.00-0.05m layer of all treatments was lower (11.1-33.5 %) and OM contents were higher (191.7-291.7 %), than in T7 (Table 2). A good vegetation cover of the soil prevents or reduces the direct action of raindrops, helping to create a more favorable environment for aggregation (Campos et al., 1999) through the dry matter input of the above- and below-ground parts of the cover crop.

The higher compaction in the 0.10-0.15 m layer was also confirmed by the smaller differences between the treatments (T1 to T6) and T7, indicating that the conditions in the subsurface layer were less favorable for the development of cover crops (Table 2). In relation to T7, the grass treatments differed by 2.9-8.5 % in the percentage of macroaggregates and 11-54.5 % for MWD. This result was due to the excessive compaction

Table 2. Mean percentages of macro and microaggregates, mean weight diameter (MWD), bulk density (BD), total porosity (TP), macroporosity (Ma), microporosity (Mi) and organic matter (OM) for all experimental treatments with reconstructed soil in a coal mining area and their differences from the control (bare soil) in the layers 0.00-0.05 and 0.10-0.15 m

Treat.	Macroaggregate	Microaggregate	MWD	BD	TP	Ma	Mi	OM
	%		mm	Mg m^{-3}	m^3 m^{-3}			%
			0.00-0.05 m					
T1	70.16 b	29.85 a	1.43 b	1.48 a	0.45 a	0.08 a	0.37 a	1.05 b
Δtest (%)	+7.1	-13.5	+58.9	-3.9	+7.1	+ 33.3	+2.8	+191.7
T2	75.26 a	24.74 ab	2.00 a	1.39 a	0.47 a	0.08 a	0.39 a	1.18 b
Δtest (%)	+14.9	-28.3	+122.2	-9.7	+11.9	+ 33.3	+8.3	+227.8
T3	70.82 b	29.19 a	1.44 b	1.43 a	0.46 a	0.08 a	0.38 a	1.41 a
Δtest (%)	+8.1	-15.4	+60.0	-7.1	+9.5	+33.3	+5.6	+291.7
T4	77.08 a	22.93 b	1.70 ab	1.41 a	0.47 a	0.10 a	0.37 a	1.32 a
Δtest (%)	+17.7	-33.5	+88.9	-8.4	+11.9	+ 66.7	+ 2.8	+266.7
T5	75.51 a	24.49 ab	1.86 ab	1.42 a	0.46 a	0.08 a	0.38 a	1.33 a
Δtest (%)	+15.3	-29.0	+106.7	-7.8	+ 9.5	+ 33.3	+5.6	+269.4
T6	72.16 ab	27.85 a	1.53 ab	1.41 a	0.46 a	0.09 a	0.37 a	1.16 b
Δtest (%)	+10.2	-19.3	+70.0	-8.4	+9.5	+50.0	+2.8	+222.2
T7	65.50	34.50	0.90	1.54	0.42	0.06	0.36	1.05
T8[(1)]	82.70	17.30	3.68	1.42	0.41	0.01	0.39	3.89
			0.10-0.15 m					
T1	81.48 a	18.52 a	1.71 a	1.56 a	0.43 a	0.08 a	0.34 a	0.94 a
Δtest (%)	+2.9	-11.1	+11.0	-7.7	+13.2	+166.8	-2.9	+168.6
T2	82.18 a	17.82 a	2.00 a	1.60 a	0.42 a	0.05 a	0.35 a	0.95 a
Δtest (%)	+3.8	-14.5	+29.9	-5.3	+10.5	+66.7	0.0	+171.4
T3	84.35 a	15.64 a	1.76 a	1.65 a	0.38 a	0.05 a	0.32 a	0.95 a
Δtest (%)	+6.6	-25.0	+14.3	-2.4	0.0	+66.7	-8.6	+171.4
T4	82.08 a	17.93 a	2.38 a	1.57 a	0.41 a	0.06 a	0.34 a	0.93 a
Δtest (%)	+3.7	-14.0	+54.5	-7.1	+7.9	+100.0	-2.9	+165.7
T5	85.92 a	14.08 a	2.04 a	1.58 a	0.41 a	0.05 a	0.36 a	0.94 a
Δtest (%)	+8.5	-32.4	+32.5	-6.5	+7.9	+66.7	+2.9	+168.6
T6	83.95 a	16.05 a	1.85 a	1.60 a	0.39 a	0.05 a	0.34 a	0.79 a
Δtest (%)	+6.1	-23.0	+20.1	-5.3	+2.6	+66.7	-2.9	+125.7
T7	79.16	20.84	1.54	1.69	0.38	0.03	0.35	1.12
T8[(1)]	80.13	19.87	3.20	1.48	0.39	0.05	0.34	2.77

[(1)] Nunes (2002). T1: *Cynodon dactylon* cv vaquero; T2: *Urochloa brizantha*; T3: *Panicum maximun*; T4: *Urochloa humidicola;* T5: *Hemarthria altissima;* T6: *Cynodon dactylon* cv tifton 85; T7: bare reconstructed soil; T8: natural soil. Equal lower-case letters in a column are not significantly different from each other (Tukey test, p<0.05); Δtest (%): increase (+) or decrease (-) in relation to control T7.

of reconstructed soil during the topographic reconstruction of the area, making the environment less favorable for root development (Darmody et al., 2009), since the compaction of the soil particles raises soil BD and reduces Ma, making the plants more susceptible to water stress, and limiting the capacity of nutrient uptake, mainly in the subsurface layers (Conte et al., 2011).

The BD in the 0.10-0.15 m layer of the grass treatments was 2.4-7.7 % lower than in the bare reconstructed soil (T7) whereas Ma was 66.7-166.8 % higher than in T7 (Table 2). This may be related to the cracks generated by wetting and drying cycles, which is common in clay soils. Compaction causes a rearrangement of aggregates in a massive structure, which is also characterized by the presence of vertical and horizontal cracks or fissures (Horn et al., 1995) caused by repeated wetting and drying cycles (Horn et al., 1994). On the other hand, these cracks can provide natural pathways for root growth in compacted soil layers (Ball et al., 2005).

The results of this study show that the effect of cover crops on aggregation of reconstructed soil will require a longer time for the formation of stable aggregates mainly by biological action. The improvements to date, shown by the differences between the treatments T1 to T6 and control T7, indicate the initial action of the root system associated with the soil internal forces (wetting and drying cycles). The roots must be causing the rupture of the cohesive mass, so that at a later time, the same roots can be reagreggated through root exudation, increased organic matter and microbial activity of the soil, especially in the surface layer of the reconstructed soil. According to Horn et al. (1994), soil aggregation depends on the capillary forces, the number of wetting and drying cycles, mobility of mineral particles, binding energy between particles and/or between aggregates, biological activity, and the chemical composition of the soil solution and organic constituents.

Based on the reference area of natural soil adjacent to the mining area under native vegetation (T8), the soil macroagregation in the grass treatments was on average 11.13 % lower, MWD 54.89 % lower and the OM content 68.08 % lower in the top soil layer. In the subsurface layer, despite the 3.99 % higher macroagregation in the grass treatments than in T8, MWD was 38.85% lower and OM content 66.91 % lower (Table 2). These differences in aggregation were expected because under natural conditions the soil organizes itself over time in a well-defined structure by pedogenic processes, according to the given environmental conditions (Vezzani & Mielniczuk, 2011). However, with the vegetation removal and total profile destruction there was a rupture of this process in the reconstructed soil, leading to the mixing of the soil horizons and consequently the disruption of aggregates and their exposure to the action of decomposers (Ussiri & Lal, 2005). The great differences between the natural and reconstructed soil therefore suggest that the recovery of the structural conditions of the new soil will be slow, according to the intense degradation caused by surface mining.

It is noteworthy that the horizons with the sequence A-AB-BA-Bt-BC in the Lixisol profile (before mining) differed from each other in thickness, color, texture, structure, etc., and Bt is significantly more clayey than the other horizons (Nunes, 2002). After the topographic reconstruction of the mined area, the profile of the studied reconstructed soil consisted of only the Bt horizon on top of the mine waste (unworkable material). Consequently, the structural conditions of the reconstructed soil will probably evolve in another direction than the natural soil used as reference.

CONCLUSIONS

1. The higher values of macroaggregates and mean weight diameter in the 0.10-0.15 m layer compared to the 0.00-0.05 m layer of the reconstructed soil resulted from the high degree of compaction caused by heavy machinery traffic on the clay soil layer.

2. After 24 months, the soil aggregation was improved in all grass treatments, compared to the reconstructed soil without vegetation (control), mainly in the surface layer, particularly in those with the cover crops *Urochloas* and *Hemarthria altissima*.

3. The great differences between the treatments with grasses and natural soil (reference) indicate that it could take decades to recover the structure conditions of the soil prior to mining.

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